THE SCIENTIFIC MONTHLY

JANUARY, 1942

REPAIR AND RESISTANCE OF TISSUE IN LIFE PROCESSES[1]

By Dr. WM. deB. MacNIDER

KENAN RESEARCH PROFESSOR OF PHARMACOLOGY AND DEAN OF THE MEDICAL SCHOOL,
THE UNIVERSITY OF NORTH CAROLINA

THE life processes operating in and through tissues are being shown by experimentation to be dependent upon both highly specific as well as generalized chemical influences. These specialized chemical actions may become effective at such a high magnitude of dilution that their chemical measurement or assay assumes difficulties unless this measurement be indicated by some quantitative functional expression. Chemical and physical changes in the gross have lost their significance and attraction as through research the importance of the infinitesimally small has been appreciated. For example, the stimulation of nerve tissue, such as that of the vagus nerve supplying the heart with a portion of its fibers, is now known to exert its slowing influence, not by the action of some ill-defined nerve impulse effect, whatever this may be, but to the liberation as a result of the stimulation of a highly specific chemical body effect in a dilution of high degree which is responsible for the cardiac influence. A similar statement may be made for the stimulation of certain nerves which accelerate the heart. We pass from the gross and apparent of nerve stimulation to the meticulous and specific in terms of chemical action.

The amazing influence of vitamins and the different components of a specific vitamin, illustrates not only the specificity of chemical action for a given tissue, but may include a more generalized tissue influence. The use of nicotinic acid in pellagra is perhaps the most astounding example of the generalized influence of a chemical on tissues when these tissues are attempting to live with a deficit of a chemical body having a common action for a variety of living and damaged cells. In pellagra the bilateral and characteristic skin lesions of the hands and forearms rapidly subside, the acutely inflamed tongue and mucous lining of the mouth become normal in appearance, the exhausting symptom, diarrhoea, subsides and finally this simple chemical body, acting in or on brain cells, may in a few hours transform a senseless, maniacal individual into one with sense, and sense with reason. Pharmacology, operating through physical and organic chemistry as that biological science which concerns itself with the chemical and physico-chemical action of substances other than the usual food materials in normal and also in pathological tissues, has a domain of very great importance in attempting to eluci-

[1] The first of a series of three articles on "Tissue Susceptibility and Resistance" to be contributed by the author.

date the mechanism of chemical action, both in normal tissue as adjusted life and in diseased tissues as maladjusted life. Such a position of importance for this science in the medical curriculum has in no small way been due to the medical school of the University of Michigan, for here the labors of Abel, Cushny and Edmunds were of such an order of understanding as to create not only a body of facts but ideals translated through facts as pharmacology which have extended themselves far beyond the confines of this campus.

The function of pharmacology is not only to acquire highly specialized information as to chemical, drug action, in normal tissue but to obtain knowledge of this same type of action in pathological tissues attempting to operate under the strain of disease. The object of such inquisitiveness is two-fold. First, through research to obtain facts as isolated and detached as these facts may be, and secondly, certainly from the medical student's point of view, to be able to apply these facts for the modification of maladjusted physical states in the hope that such changes may be induced in tissues which will enable them to relate themselves to that environment in which they must at least attempt to function. The difficulty of such investigation is apparent. Even for normal tissues with a knowledge of the constitution of the chemical to be used in the reaction, our understanding of the chemistry of the living stuff in which such a chemical body is to act is extremely limited. It is as though we placed in a test-tube or beaker a chemical substance of known structure and then superimposed on it a body of unknown composition, watched the reaction in the gross and then attempted to explain its chemical detail. Such difficulties become greatly increased when we attempt to explain chemical action in pathological tissues, tissues that have departed from the normal through processes of degeneration, but which may through chemical and physico-chemical developments either so recuperate or repair themselves physically and chemically that states of normal susceptibility, increased susceptibility or an acquired resistance to injury may develop within them.

As life flows on in cells and in similar aggregates of such units designated organs, processes of molecular disintegration and of synthesis go on in a more or less balanced relationship. These processes give rise to certain manifestations of cell life designated function. A state of imbalance in these forces not infrequently arises as a result of changes developing within such units as produced by chemical action from without on such units which lead to changes of such a gross order that they may be microscopically recognized and as such are designated changes of degeneration. Whether or not such changes going to such a point as may be determined by the nature of the cell are entirely harmful, or whether they may serve to modify and repress function and induce rest, is an interesting question, which will be considered later. We in our arrogance at least assume that such changes are harmful and that they should be made to return to what we consider the normal as early as possible. This may not be wisdom. In such injured cells with a modification of function there is likely an inherent urge within them to reconstitute their structure. We know little chemically concerning the degenerations. Our knowledge of the chemical processes indicating an attempt at reconstitution is virtually lacking. Whatever may be the chemical nature of these latter changes they are indicated in their development either by cell recuperation or cell regeneration. In the former process the cells return to a morphological normal without the formation of new cells. In the latter type of repair new cells are

formed by cell division to take the place of those units so severely injured that changes of recuperation have become ineffective as a process of repair. The factors determining what form of repair process will be instituted are impossible to state. The type of cell, its location, the severity of the injury and the age of the animal in which both the injury and the repair state develop have to do with these changes. Furthermore, it is not known what determines the physical integrity of such cells of repair to subsequent injury except in a very gross manner in that, if the injured cells by employing either process of repair or a combination of the two processes returns to the morphological normal for this cell type, there is usually no evidence of an acquired resistance. The repaired cell's chemical affinity for injurious chemical agencies has not been altered. If, however, the repair process leads to a morphological alteration in cell type, which type still possesses a certain degree of function normal for it, the chemical constitution of such repaired cells or newly formed cells may be of such an altered chemical nature as to withstand deleterious chemical action.[2,3,4,5,6,7]

The susceptibility of tissues to injury, the type of the injurious process in terms of its severity and chemical nature depends to an extent on the concentration of the toxic chemical substance and the affinity which a given cell type has for it. One of the radioactive elements, uranium, used in the form of the nitrate has the ability to injure epithelial tissue such as is found in the liver and in the kidney. In the liver this injury is of a diffuse order, affecting uniformly all the epithelial secretory cells of the organ. In the kidney the action of the poison is selective in that it picks out the epithelial cells of the proximal convolution of the nephron to exert its toxic influence. In the normal dog the severity of this action is determined in part, and only in part, by the dosage of the poison. When such animals are given 2 mgs of uranium nitrate per kilogram the kidney shows functional evidence of injury by the appearance of albumin casts and red blood cells in the urine, by a rapid reduction in the output of phenolsulphonephthalein in the urine and after an initial increase in the volume of urine, by a decrease which may progress to a transitory anuria. The reserve alkali of the blood is reduced and there is a moderate retention in the blood of urea, nonprotein nitrogen and rarely creatinin. Such animals usually recover and do not show evidence of a permanent kidney injury. If afforded nourishment, fluid and warmth a process of repair is accomplished with a return of normal kidney function. Perhaps we fail to appreciate the innate tendency on the part of tissues to repair themselves perfectly and to function with adjusted beauty.

The changes of degeneration in such kidneys consist in cloudy swelling of the epithelium in the proximal convoluted tubule, rarely vacuolation of the cytoplasm and an increase in stainable lipoid material in such cells with a degree of nuclear injury which is variable. The brush borders of such injured cells disappear and the mitochondrial arrangement is different from that found in the normal cell. Within eight to fourteen days following an injury to the kidney from uranium of this degree of severity, a repair process has developed which results in sufficiently injured cells, in the formation by cell division of new cells identical in structure to the normal cell found in this location of the tubule. If

[2] Wm. deB. MacNider, *Jour. Exp. Med.*, 49: 387, 1929.

[3] *Ibid.*, *Jour. Exp. Med.*, 49: 411, 1929.

[4] *Ibid.*, Harvey Society Lectures, 24, 82, 1928–29. The Williams and Wilkins Co., Baltimore.

[5] *Ibid.*, *Science*, 73: 103, 1931.

[6] Thomas Francis, Jr. and C. H. Stuart-Harris, *Jour. Exp. Med.*, 68: 789, 1938.

[7] Thomas Francis, Jr. and C. H. Stuart-Harris, *Jour. Exp. Med.*, 68; 803, 1938.

at such a period the animal be re-intoxicated with an amount of uranium nitrate similar to that used for the first intoxication, there is no evidence that this normal epithelium of repair has developed an acquired resistance to this substance. The newly formed cells participate in the same type of degenerative process which may be of a more severe order than that induced by the initial injury. The animals which survive affect such a survival in so far as the kidney is concerned by the formation of a normal type of epithelial structure. These experiments would indicate that an injury to renal epithelium of the order and magnitude indicated is insufficient to so upset the chemical constitution of such cells as shown by cell changes that they can not repair themselves true to form and with such a normal chemical nature to retain their affinity for the toxic expression of the influence of uranium nitrate.

In another series of animals an intoxication has been induced by the use of a larger amount of uranium nitrate, four milligrams per kilogram. A certain percentage of such animals succumb from a combined renal and hepatic type of death. Those animals which survive show from biopsy material obtained from the kidney a severer type of epithelial injury to the cells of the convoluted tubule than has been described for the first group of animals. In this latter, more severely intoxicated group, the changes in the epithelium extend from that of cloudy swelling and a coarsely granular degeneration to one of cytoplasmic necrosis associated with the accumulation of stainable lipoid material as fused masses or droplets. The nuclear changes are variable and important. In some areas involving the space in the tubule normally occupied by from two to ten or more cells there may be not only a disappearance of the nuclei, but of cell cytoplasm as well. The basement membrane in such areas alone persists. In other areas where cell damage is severe but not complete, fragments of nuclear material staining intensely are to be found within the preserved nuclear membrane. In such locations the injured nuclei are covered with cell substance. Such an order of tubular degeneration in association with the glomerular injury is expressed functionally by a marked reduction in urine formation or an anuria, a high percentage of albumin in the urine as the state of anuria is approached, numerous fragments of granular and fatty casts, glucose and ketone bodies. The urine usually fails to show the presence of phenolsulphonephthalein, while the blood indicates a high degree of retention of blood urea, nonprotein nitrogen and in the more severely injured animals a retention of creatinin. Recovery is variable and prolonged in such a group of severely intoxicated animals. The use of glucose and warmth appear to facilitate this process. In such animals as effect a recovery, the changes of repair in so far as the renal tubules are concerned is by a process of cell division, the newly formed cells arising from those cells which have been severely damaged but not damaged to the point of chromatic and nuclear dissolution. In such cells the first change is either a rearrangement of the chromatic material within the nucleus or its synthesis prior to cell division. These newly formed cells, arising as a repair process from severely damaged cells, are not of a normal order for this segment of the tubule. They are flattened, the nucleus is large in proportion to the enveloping cytoplasm and both nuclei and cytoplasm stain evenly and intensely. From such areas of new and atypical cell formation there occurs an ingrowth of such structures into those areas of the tubule divested of epithelial substance. This occurs along the course of the intact basement membrane. Such ingrowths are at first syncytial and may remain

syncytial. Usually such structures show perfect or imperfect cell differentiation. The length of such new cell formations is much greater than that of cells normal for this portion of the tubule. As this type of atypical cell repair is developing in the tubules, the glomeruli commence a process of periglomerular and intracapillary fibrosis. Such glomerular changes reflect themselves in terms of renal function. To date, in the mammalian kidney it is impossible to differentiate tubular and glomerular function except by inference.

The interest and significance of this atypical type of repair which may be induced in a kidney severely injured by uranium does not rest with the repair process alone, with the apparent reversal of this tissue through repair to tissue of an embryonic order. It assumes importance when the observation is made by secondary injections of uranium in the amount initially used, four milligrams per kilogram, or when this substance is even increased in dosage to six milligrams per kilogram that the altered atypical epithelium of repair is resistant to such degrees of intoxication, whereas epithelium of a normal order in the same location of the tubule was specifically and highly susceptible to this chemical agent. The experiments indicate that if this epithelial tissue be both severely and also sufficiently injured, the life mechanism in such injured cells is unable to effect an epithelial repair of a normal order. The repair process is of an abnormal, atypical order which partakes of certain embryological characteristics. Such a repair process imparts to these fixed tissue cells a high degree of resistance to subsequent injury. Life and resistant life perhaps of a lower order of functional effectiveness has been established as a result of cellular injury resulting through repair in a shift in cell morphology. Such changes are of a gross, structural order and it is not justifiable to assume that the acquired resistance necessarily depends upon change of form. It must depend upon a change in chemical constitution which in these experiments has been associated with a shift in cell type. This thought is strengthened and for cells in general given a significance by the work of Bunting and Longley,[8] which has shown that the rat kidney may develop a high degree of resistance to arsphenamine without a change in cell type, and by that of Selye,[9,10] who has recently demonstrated an acquired resistance of the mouse kidney to bichloride of mercury following a protection afforded by the subcutaneous injection of testosterone. A resistance of the dog kidney to bichloride may be obtained following a repair of the kidney from a severe uranium injury.[11]

Earlier in this discussion it was stated that the liver participated in a uniform type of epithelial injury when uranium nitrate was given subcutaneously. The following observations have been made concerning both the changes of degeneration in the liver and the processes of repair, which latter changes may not only afford the liver protection against uranium but also an acquired resistance to substances far removed in their chemical constitution from uranium.[12,13,14]

The changes of repair which develop in the liver when an animal is intoxicated with different amounts of uranium need not be given in detail here, for the principles involved in these processes of repair are similar to those which have been given in detail for the kidney. A slight

[8] C. H. Bunting and B. J. Longley, *Jour. Pharm. and Exp. Therap.*, 69: 171, 1940.

[9] Hans Selye, *Jour. Urology*, 42: 637, 1939.

[10] *Ibid., Jour. Pharm. and Exp. Therap.*, 68: 454, 1939.

[11] Wm. deB. MacNider, *Proc. Soc. Exp. Biol. and Med.*, 37: 90, 1937.

[12] *Ibid., Science*, 81: 601, 1935.

[13] *Ibid., Jour. Pharm. and Exp. Therap.*, 56: 359, 1936.

[14] *Ibid., Jour. Pharm. and Exp. Therap.*, 56: 373, 1936.

injury of a diffuse order to the liver induced by uranium is followed by repair accomplished by cell division in which process cells of a normal type are formed. When the epithelium is more severely damaged by a higher dosage of uranium and apparently damaged to a point which prevents a normal type of new cell formation, flattened and atypical cells, or syncytial structures, develop to in part or completely reconstitute the cords of liver cells which in large measure make up the liver lobules. If the repair to the liver has been accomplished by the formation of a normal polyhedral type of cell there is no evidence of an acquired resistance to subsequent uranium nitrate intoxications. If the repair has been effected by the formation of the atypical type of cell there develops not only an associated resistance to uranium, but to other chemical bodies usually possessing a marked hepatoxic influence. Such resistance may not be permanent.

Chloroform is a chemical agent highly effective in its toxic action for the liver and elects to act in this capacity on hepatic epithelium in the central portion of the liver lobule. In this location it is able in a properly prepared animal to induce an epithelial necrosis with fatty degeneration in contiguous areas of the lobule. Many years ago the fact was demonstrated by Whipple and Sperry[15] that if a dog was starved for twenty-four hours and given chloroform by inhalation for one and one-half hours, a central necrosis of the epithelium of the liver lobule invariably occurred. In the experiments now to be presented two groups of animals were employed to ascertain whether or not, following a uranium intoxication, the liver had acquired a fixed celled resistance to this certainly acting hepatoxic agent, chloroform. The first group of dogs were represented by those animals that had recovered from a moderately severely uranium intoxication, and which had effected a liver repair by the formation of a normal type of epithelium. When such animals were starved for twenty-four hours and given chloroform by inhalation for one and one-half hours they invariably developed a central necrosis of the liver lobules which was variable in its extent. The second group of animals was represented by those dogs which had recovered from a much severer uranium intoxication and which had from a study of biopsy material from the liver repaired this organ by the formation of the flattened and atypical, yet functionally effective form of epithelium. When animals of this group were starved for twenty-four or even forty-eight hours and given chloroform, not for one and a half hours, but for as long a period as three hours, the morphologically altered and atypical epithelium was found to maintain a structural resistance to the toxic action of this certainly effective agent, chloroform, when used in animals with a normal type of hepatic epithelial tissue. Such cellular resistance may not be of an absolute and permanently continuous order. These atypical cells are living units and likely even in their altered form and chemical constitution they have, through this life, evolved over long periods of time the urge to assume their normal form and normal chemical constitution. Such thoughts find substantiation from two sources. If animals possessing such atypical cells which have demonstrated their acquired resistance be subjected to a period of starvation for forty-eight hours and be then exposed to the action of chloroform for periods of three hours on two successive days, the early changes of hepatic injury develop in the central portions of the liver lobules. And furthermore, a certain number of these animals that have shown persistent epithelial resistance may after a period of months fail to show it in certain re-

[15] G. H. Whipple and J. A. Sperry, *Bulletin Johns Hopkins Hosp.*, 20: 278, 1909.

stricted areas of the liver lobule. These are areas in which a reversion to a normal cell type has occurred and it is assumed with such a change in form a change in chemical constitution has also developed which renders such normal epithelium once more susceptible to the toxic action of chloroform. In areas in the same liver lobules in which no reversion of cell type to or towards the normal has developed, the atypical epithelium retains its acquired resistance.[16]

SUMMARY

1. This presentation concerns itself in the first place with an acknowledgment of our lack of knowledge of the chemistry of living tissues and therefore, even though we may have exact understanding of the chemical structure of a body introduced into such tissue, we may experience great difficulty in explaining how such a substance acts in normal tissue and even greater difficulty in grasping its mode of action in pathological tissue.

2. Such a concept may be demonstrated experimentally. Observations have been presented in connection with cell injury and repair to both the kidney and the liver that epithelial cells in the proximal convolution of the nephron and such cells in the liver as a whole have such a chemical constitution as to render them susceptible to the toxic action of uranium nitrate. When such cells in these two organs undergo repair, this process may result in the formation of morphologically altered types of cells and cells which afford some evidence of a change in their chemical nature. These structures have not only acquired a resistance to the chemical agents which induced an injury to be followed by the altered cell type formation, but to chemical bodies entirely different in constitution from that body which through injury developed cell resistance. Cell repair effected by a normal type of cell formation and in the liver with a normal degree of function has no resistance to these injurious agents.

3. These observations should be considered of a very superficial and gross order and their significance should not be overshadowed and dominated by a morphological concept of resistance due to change in form as such. Cell form may be an associated, but not the significant factor in this type of acquired tissue resistance. Through changes in cell form the influence of physical forces may be modified which influence cell life by acting as such or which at the same time influence the readiness with which chemical bodies enter cells and also the ease with which they escape from such units. Such changes in cell form may in part determine chemical concentration within cells. Of more importance than a consideration of form is an understanding of the shifts in the chemical nature of cells when through a process of repair they either acquire or fail to develop a resistance to chemical substances. Research, not only of a pharmacological, but of a broad and fundamental biological order is necessary in this domain of fixed cell susceptibility and acquired cell resistance.

16 Wm. deB. MacNider, *Jour. Pharm. and Exp. Therap.*, 59: 393, 1937.

BAD EARTH

By Dr. SAM F. TRELEASE
PROFESSOR OF BOTANY, COLUMBIA UNIVERSITY

Poisonous wheat and corn grown on fertile soil were virtually unknown to the scientist as well as to the general public until about seven years ago. At that time it was announced that grain from certain sections of the great cereal-growing region of the north central plains harbors the cause of a serious and sometimes fatal disease afflicting livestock and perhaps also man. We learned that farm animals get the disease from eating hay and grain raised in the affected areas, and it was intimated that flour and other mill products made from the grain might poison human beings.

Although little has been published on the subject until very recently, a serious disease of livestock has been recognized for many years by the inhabitants of certain parts of South Dakota and Nebraska. It came to be known as "alkali" disease because of a supposed relationship to alkali, or mineral salt, in the water or soil. The earliest account of the malady is to be found in a report written in 1856 by T. C. Madison, an army surgeon, who described the symtoms of a fatal disease that afflicted the cavalry horses at Fort Randall, then in the Territory of Nebraska but now included in South Dakota. He attributed the disease to the pasturage.

Marco Polo may have been referring to the same disease when he wrote, in about 1295, of a poisonous plant in Turkestan, which, if eaten by "beasts of burden," caused their hoofs to drop off.

A. T. Peters in 1900 investigated alkali disease in Boyd County, Nebraska, where it had been prevalent among all kinds of livestock since the settlement of that region in 1891. Although Peters erroneously concluded that only moldy corn was responsible, he reported testimony of farmers which involved sound corn, other grains and pasturage. In a brief account of the disease in South Dakota, C. C. Lipp in 1922 stated that farmers were convinced that forage plants store a sufficient quantity of minerals to cause the disease.

In 1929 K. W. Franke, of the South Dakota Experiment Station, began a series of investigations which led to the discovery of selenium as the cause of alkali disease. His first publication on the subject, in 1934, demonstrated that grain raised on certain soil areas was highly toxic to animals. The next step was to discover, if possible, the nature of the poison. In May, 1931, at a meeting of an interbureau committee in Washington, H. G. Knight is said to have suggested that selenium be looked for in the grain. W. O. Robinson was furnished a sample of toxic wheat from South Dakota. He analyzed the wheat and in 1933 published a report stating that it contained minute concentrations of selenium—equivalent to only 12 pounds of selenium in a million pounds of wheat. Traces of this element were also found in soils producing toxic grain.

A preliminary field survey of alkali disease of livestock was published in 1934 by K. W. Franke and others. The survey included the regions from which this type of poisoning had been reported—namely, central and western South Dakota, northern Nebraska and the eastern edge of Wyoming. The native flora of the regions where the malady occurred was not observed to be different from that of adjoining areas.

Since the days of the earliest settlers poisonous plants have taken a heavy toll

of cattle and sheep throughout the vast grazing areas in fifteen of the western states. In many cases the identity of the plants responsible for the losses remained unknown for a long time. Even after demonstrating that certain plants were poisonous, state and federal investigators spent many years in futile attempts to ascertain the nature of the elusive toxic principle. To illustrate the magnitude of the losses, some examples may be cited: During the summers of 1907 and 1908 more than 15,000 sheep died in a region south of Casper, Wyoming, of acute poisoning attributed to woody aster and Gray's vetch. In 1930 about 340 sheep that had eaten two-grooved vetch died near Elk Mountain, Wyoming, within twenty-four hours. During the same year this plant caused the death near Rock River, Wyoming, of 125 sheep, 75 of which succumbed in a single night. In 1931 a flock of 200 sheep was pastured over night in a small gulch southwest of Pueblo, Colorado; in the morning 197 of these were dead. A year later 71 sheep, out of a flock of 157, died in the same gulch.

An outstanding feature of range poisoning is its restriction to limited but widely scattered regions, called poison areas. The most common causes advanced by stockmen to explain these poison cases have been alkalies and alkali water, poisonous gas arising from the soil or vegetation, and malicious poisoning by means of bad salt, bait or arsenic in the ponds. In an attempt to solve the problem, the Wyoming Experiment Station in 1921 drew up a project to study "an obscure disease of cattle on the range." Although the work continued until 1930, no evidence was obtained that could explain the cause of range poisoning in cattle.

The nature of the poison responsible for the wide-spread losses of cattle and sheep in the western states remained an unsolved mystery until O. A. Beath and his associates at the University of Wyoming discovered in 1933 that certain wild plants on the ranges were able to absorb and accumulate large quantities of selenium when they grew on certain types of soils. Eight species of native indicator plants were found, the selenium content of which was definitely correlated with the geological formations on which they were collected.

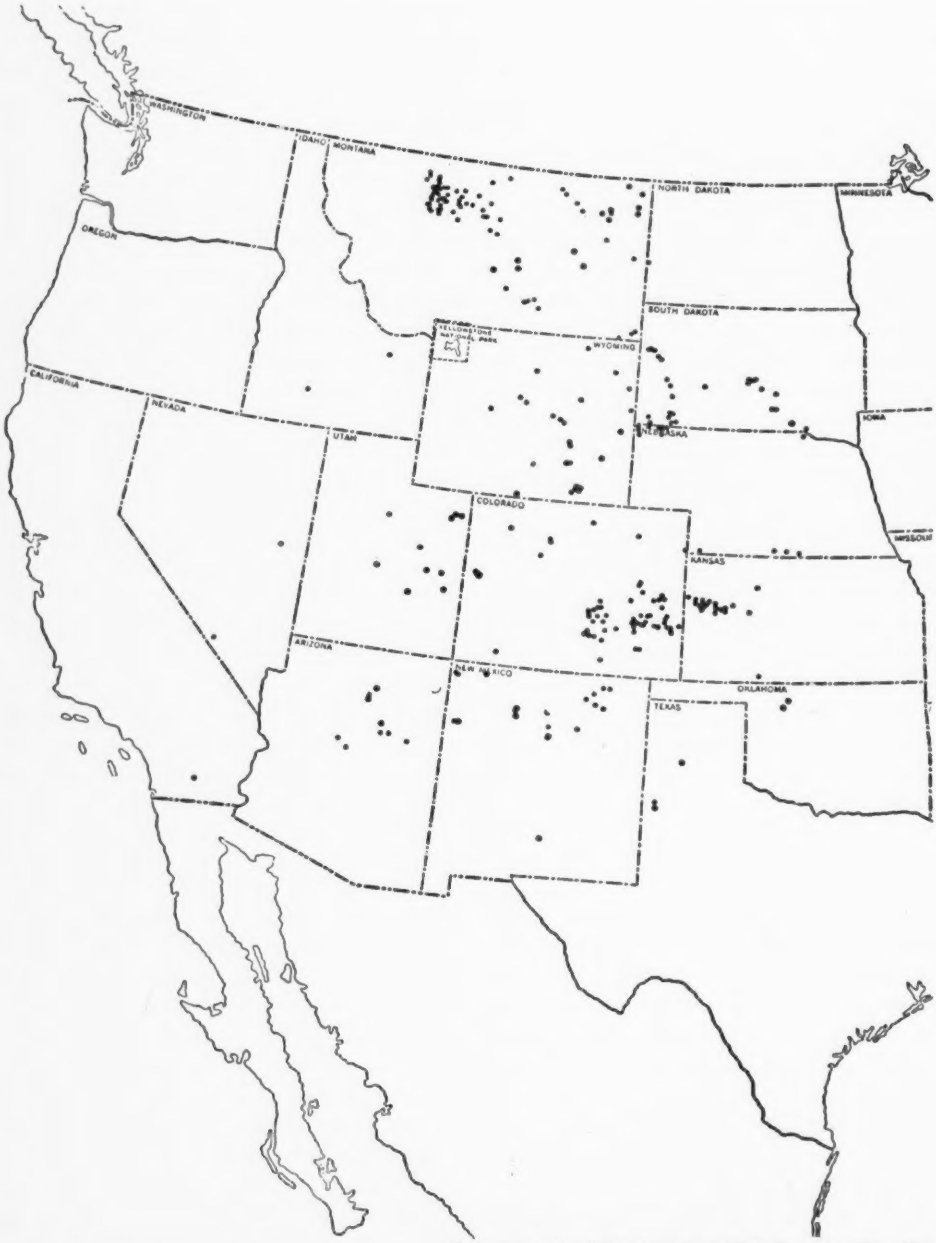
In 1935 H. G. Byers began the publication of a series of reports on the occurrence of selenium in soils and vegetation.

The present article is based on a review of the literature, supplemented by observations in the field and in the laboratory.

The Element Selenium

The chemical element selenium, discovered in 1817, resembles sulfur in chemical properties and reactions. In physiological action, however, there is a vast difference between the two closely related elements: sulfur is an essential constituent of all living substance, whereas selenium is as powerful a poison as arsenic, and it enjoys the unenviable distinction of being the only mineral element absorbed by food plants in sufficient quantities to make them lethal to animals.

Selenium occurs in many parts of the world. It has long been known to be associated with sulfur and to be present in ores of copper, iron and lead. Many rocks and soils of diverse origin have recently been shown to contain minute concentrations of this element. It is obtained commercially as a by-product of electrolytic refining of copper. About 100 tons of domestic and an equal amount of imported selenium are used annually in manufacturing processes. Selenium is used as a decolorizer in the manufacture of glass, and as a red or orange coloring matter in the production of glass, glazes, paint, ink and plastics. It is also employed in alloying steel and copper, in manufacturing rubber, in fireproofing electric cables and in making photoelectric devices.



Base map copyright, American Map Co., Inc., New York

MAP SHOWING DISTRIBUTION OF HIGHLY TOXIC VEGETATION

EACH DOT REPRESENTS THE PLACE OF COLLECTION OF A PLANT SPECIMEN CONTAINING MORE THAN 500 PARTS PER MILLION OF SELENIUM.

Nature of Selenium Poisoning

The form of selenium poisoning known as alkali disease manifests itself in horses, cattle and hogs by emaciation and stunted growth. There is usually some loss of hair, particularly from the mane and tail of horses. The most striking symptom is deformity of hoofs, followed in

severe cases by the sloughing off of the old hoofs and the growth of a new set. Severely alkalied animals die or have to be destroyed. In poultry the malady results in eggs that either do not hatch or else give rise to weak chicks with ruffled, wiry feathers.

The economic consequences have been disastrous in localities where the disease is severe. The raising of horses, cattle, hogs and poultry has been discontinued, and only tractor farming of small grain is carried on. Grain known to have been produced in certain districts must be sold at a discount, and diseased animals bring low prices when marketed. Owners of some of the farms have abandoned them, not being able to finance, lease or sell them. New renters, often uninformed of the conditions, have had heavy losses soon after moving to such farms.

It has been demonstrated by experiment that plants are able to absorb enough selenium from the soil to make them highly toxic to animals. A concentration of this element as small as 1 part (by weight) per million parts of the soil, added as sodium selenate (or selenite) or as a water extract of seleniferous plants, permits growth and maturation of wheat, barley and buckwheat, with no visible symptoms of injury to them. But when the grain or straw from these plants is added to a balanced diet and fed to white rats, it produces severe poisoning. Food containing as little as 5 parts per million of selenium derived from plants stunts the growth of these animals; 20 ppm in the diet brings about death in approximately six weeks; 65 ppm is lethal in about one week. Similar poisonous effects on rats have been observed when sodium selenite, instead of toxic plants, is added to the food. But for reasons not fully understood, inorganic salts seem to be somewhat more toxic than naturally occurring organic compounds, and they lead to less retention of selenium in the animal tissues. Nor has it been possible by administration of inorganic salts to produce conspicuous malformation and sloughing off of hoofs of horses, cows and hogs.

Grain from farms with affected livestock has been used in extensive feeding tests on white rats at the South Dakota Agricultural Experiment Station. The grain includes corn, wheat and barley. Although the grain has no unusual odor or taste, it is poisonous to rats, producing anemia, liver lesions and other characteristic symptoms. The most toxic grain contained about 30 parts per million of selenium and produced very severe effects, bringing about death of 50 per cent. of the rats within 50 days, and 90 per cent. within 100 days. Less toxic grain caused death after a longer period of time; and the least toxic brought about only growth retardation.

When rats were given a choice between diets having various concentrations of selenium (natural or sodium selenite), they invariably chose the least toxic food, possibly basing their selection on taste or odor imperceptible to man. It is commonly believed by cattlemen that range animals are able to recognize the seleniferous vegetation (some of which possesses a telltale garlicky odor) and eat only the least toxic.

Most of the eggs from chickens fed on toxic grains develop deformed embryos and are incapable of hatching. Chicks from the few eggs that do hatch have down that appears greasy or wiry, and they live only a short time. Similar abnormalities can be produced by injecting selenium into eggs before incubation.

O. A. Beath observed in 1932 that specimens of the native wild plant *Astragalus bisulcatus* (the two-grooved vetch) growing in some soils had an extremely offensive garlicky odor, while specimens from other soils lacked this odor. In 1934 he demonstrated that the plants with the offensive odor were more toxic than those lacking it. The difference was found to be correlated with the

selenium content of the plants. This and related species are distributed throughout many of the western states, where they are responsible for heavy losses of cattle and sheep. The deadly nature of seleniferous weeds is shown by the fact that only ten ounces of green *Astragalus bisulcatus* rich in selenium will cause death in sheep in 30 minutes. These range plants sometimes accumulate more than 10,000 parts per million of selenium. They usually contain more of the element, and hence are more poisonous to livestock, when they grow on the Niobrara, Steele or Pierre shales than when they grow on certain other shale formations, such as the Morrison, Thermopolis or Lewis.

Two somewhat different types of selenium poisoning in livestock may be distinguished—namely, alkali disease and blind staggers. Alkali disease, known only in western South Dakota and northern Nebraska, is a chronic form characterized by loss of hair and deformation and sloughing off of hoofs. Blind staggers, the predominant form of the disease among cattle and sheep on the ranges throughout the western states, represents a much more acute type of poisoning, which results in death within a comparatively short period of time. There is no sloughing of hoofs or loss of hair in typical cases of blind staggers. Both diseases, however, seem to be produced by selenium and are characterized by the same type of injury to the liver. The differences in symptoms suggest that the various selenium-bearing plants carry the element in different chemical combinations, or that the selenium may be accompanied by other toxic substances.

When present in food, selenium finds its way into all the body tissues, attaining concentrations, according to H. C. Dudley and H. G. Byers, as high as 16 parts per million in the heart, 25 ppm in the liver and 27 ppm in the blood. A tolerance for the poison can not be acquired. Although selenium is eliminated from the body in all secretions and excretions, it shows cumulative effects and produces permanent injury of the tissues. Selenium is carried in the blood stream to all parts of the body, but it is deposited chiefly in the liver, kidney and spleen (3 to 25 ppm). Concentrations of 8 to 20 ppm have also been found in the hoofs. Since the bile and the urine may contain as high as 5 to 7 ppm, excretion by the liver and the kidneys seems mainly responsible for elimination of selenium from the body. The urine of men employed in the extraction of selenium was found to contain from a trace to 7 ppm. A garlicky odor of the breath and other symptoms were noted.

Experiments with rats have shown that the toxicity of selenium (from inorganic salts or poisonous grain) is markedly reduced when the diet contains a very high proportion of protein, especially in the form of casein. But of course it would not be practicable to provide grazing livestock with such a diet.

According to A. L. Moxon, of the South Dakota Experiment Station, various arsenic compounds, supplied in the water or salt, tend to protect animals against the toxic action of selenium. Of great interest also is Moxon's discovery that the administration of bromo-benzene markedly increases the excretion of selenium in the urine and so helps the body rid itself of the poison. This detoxifying agent has recently been used with excellent results in the treatment of several cases of poisoning in man.

Loco disease is caused by alkaloids—not by selenium. A representative loco weed is *Oxytropis saximontana.* This plant usually grows on soils derived from granites, sandstones and volcanic ash. It sometimes grows on seleniferous shales, but rarely absorbs more than traces of selenium. When consumed in large quantities, it produces loco disease after about fifty days. Although the symptoms of loco disease are different from those of selenium poisoning, the two

RUINS OF THE CHAPEL AT FORT RANDALL, SOUTH DAKOTA
WHERE ALKALI DISEASE WAS FIRST REPORTED AFFLICTING CAVALRY HORSES IN 1856. THE CHAPEL WAS BUILT OF SELENIFEROUS NIOBRARA LIMESTONE.

types of poisoning are frequently confused by cattlemen.

It is evident that a low concentration of selenium in foodstuffs is a quick-acting lethal poison for mammals. Some insects also are very sensitive to selenium. Aphids are killed by concentrations in plants too low to injure the plants themselves, and red spiders are quickly destroyed by commercial insecticides containing selenium. We were surprised, therefore, to find the larvae of tiny beetles (bruchids) and wasp-like insects (seed-chalcids) destroying our supply of seeds of one of the most poisonous of the range plants, *Astragalus bisulcatus*. A second wasp-like insect was present as a parasite of the seed-chalcid. Analysis of the seeds showed that they contained 1.475 parts per million of selenium. These insects were capable of completing their life cycles on food containing about seventy times the lethal concentration for mammals.

Distribution of Selenium in Soils

Seleniferous soils and vegetation have already been discovered throughout the western half of the United States, from North Dakota to Texas and west to the Pacific Ocean. The distribution of the selenium is not uniform throughout this area, since it is confined to outcrops of certain geological formations. The affected area extends to the north and south, into Canada and Mexico, but not to the east. Further investigation will probably show seleniferous soils in many other parts of the world.

In the United States, seleniferous soils are derived, for the most part, from rocks of the Permian, Triassic, Jurassic, Cretaceous and Tertiary systems. The age of the oldest is possibly 200 million years and of the youngest 50 million years. The selenium concentration is relatively high in the Pierre, Steele and Niobrara formations of the Cretaceous. Most of the Cretaceous shales were deposited in

A TOXIC PASTURE IN A WHEAT-PRODUCING SECTION OF SOUTH DAKOTA

a shallow sea that covered the present areas of the Rocky Mountains and the Great Plains. The selenium may have come from volcanoes that were active before and during the time when the shales were being deposited. Animal life during the Cretaceous was dominated by giant reptiles. Although ferns, club-mosses, cycads and conifers were abundant, there were also many kinds of flowering plants closely resembling forms known to-day.

Botany, geology and chemistry now provide the means of locating toxic areas. If seleniferous vegetation is found on a certain geological formation, we may predict with considerable accuracy its occurrence wherever outcrops of this formation appear. Detailed surface mapping of the outcrops capable of producing toxic vegetation would be a great help to farmers and ranchers, and this should be one of the first steps in the control of selenium poisoning in livestock and man.

The outcrops of shales usually carry only 2 to 4 parts per million of selenium, of which very little is water-soluble. Soils derived from these shales may show an enrichment, which results in some cases from the solvent action of saline water and the drainage of soluble residues of selenium-bearing plants.

Seleniferous soils capable of supporting toxic vegetation are found in semi-arid regions, where the rainfall is insufficient to leach out the water-soluble selenium compounds. Cultivated crops do not significantly reduce the poison in the soil. Some of the soils that now produce toxic grain have been in nearly continuous cultivation for more than twenty-five years.

There is danger of adding selenium to soils through the use of insecticides or impure fertilizers, especially superphosphate and ammonium sulfate.

Absorption and Accumulation of Selenium by Plants

The absorption of selenium by plants depends upon the nature and concentra-

CATTLE ON A POISONOUS RANGE IN WYOMING

tion of the compounds of this element present in the soil. Moreover, different species of plants exhibit striking differences in their ability to accumulate selenium.

Some soils that contain considerable quantities of selenium are incapable of producing toxic vegetation because the element is present in unavailable forms. Chemical analyses of soils, by present methods at least, do not reveal the amounts of available selenium and so can not enable one to predict the quantities that plants will absorb. If one wishes to ascertain the capacity of a certain soil to produce toxic vegetation, one must analyze the various species of plants growing on the soil.

When rooted in the same seleniferous soil, some kinds of plants do not absorb selenium at all, while other species accumulate large quantities. Cultivated cereals, native prairie grasses and many other forage plants on the ranges show relatively slight ability to take up selenium. But several wild composites (such as the woody aster) and many species of *Astragalus* (vetches) accumulate it readily.

Selenium present in toxic grain was shown by Franke to be a constituent of the plant proteins. It replaces sulfur normally occurring in these substances.

Selenium is much less toxic to plants than to animals. Symptoms of selenium injury of plants have never been observed in the field, but dwarfing and other symptoms may be produced artificially by adding sufficient quantities of sodium selenite or selenate to the medium in which the plants are rooted. By means of water cultures and sand cultures, A. M. Hurd-Karrer and later A. L. Martin showed that the addition of an excess of a sulfate tends to decrease somewhat the absorption of selenium. This suggested that the application of sulfur to cultivated land might offer a practical means of preventing crop plants from accumulating toxic concentrations of selenium. But most of the naturally occurring seleniferous soils are

U. S. Department of Agriculture

THE CHRONIC FORM OF SELENIUM POISONING OF CATTLE

Left: COW AFFLICTED WITH ALKALI DISEASE. *Right:* DEFORMED HOOFS OF THE COW.

already saturated with sulfur in the form of gypsum, and field tests have demonstrated that the addition of more sulfur is ineffective in reducing selenium absorption.

Selenium Indicator Plants

It was discovered in 1933 by O. A. Beath and his associates that certain native plants always contain selenium when collected on seleniferous soils. These plants frequently accumulate large quantities, the highest so far recorded being 15,000 parts per million for a specimen of *Astragalus racemosus.* The selenium accumulators are known at the present time to include about 28 species of *Astragalus* (legumes with pea-like flowers) and all species so far examined of *Xylorrhiza* (woody aster), *Oonopsis* (a composite related to goldenrod), and *Stanleya* (prince's plume, of the mustard family). These plants are among the handsomest and most conspicuous of the western wild flowers.

Evidence from laboratory experiments, as well as from observations on the distribution of these plants in the field, tends to show that these species apparently require this element for their development and therefore can grow only on soils that contain it. Many of these species are abundant and widely distributed. They cover vast areas in the sparsely settled cattle and sheep sections of the western United States, and they are responsible for losses of livestock estimated at millions of dollars annually. *Astragalus racemosus* occurs from North Dakota and Wyoming southward to Texas and New Mexico. Other very widely distributed species are *Astragalus bisulcatus, Astragalus pectinatus* and *Astragalus pattersonii.* These are only the leaders among a horde of seleniferous species.

The indicator plants are an important aid in locating and mapping seleniferous areas, and they help the geologist find outcrops of certain formations. The mere presence of one of these plants indicates a seleniferous soil, and the high concentration in the plant is much more easily detected by chemical analysis than is the low concentration in the soil. Moreover, the selenium content of an accumulator collected on a certain soil gives a quantitative index of the capacity of this soil to produce toxic vegetation.

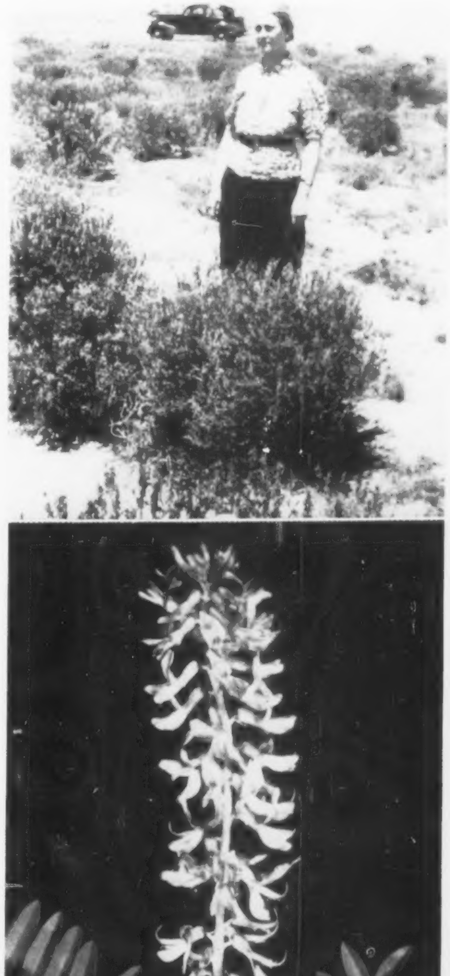
Since they give off volatile selenium compounds, these plants have a very offensive garlicky odor, the intensity of which varies with the amount of poison they contain. The odor of *Oonopsis* and of some species of *Astragalus* is so strong that it betrays the presence of the plants to one traveling in a rapidly moving automobile.

Among the selenium indicator plants, those belonging to the genus *Astragalus*

show the greatest diversity of form and the most extensive geographical distribution. This genus includes about 300 species in North America and 1,200 species in the rest of the world. Only the North American species have been examined for selenium. Field studies by Beath have shown so far that 28 of these species are selenium accumulators and indicators, whereas 54 other species absorb only small amounts of selenium and are not limited to seleniferous soils. The indicator species fall into 6 of the 29 groups into which the North American species have been divided on the basis of morphological characters. The 54 non-indicator species are found in 15 of these groups.

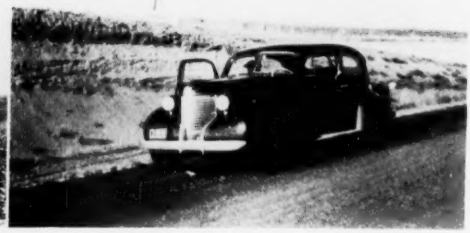
We grew two of the indicator species, *Astragalus racemosus* and *Astragalus pattersonii*, in solution cultures and sand cultures in the greenhouse. The development of these plants was greatly stimulated by selenium up to a concentration of 9 parts per million. In some tests, even 27 ppm were found to be stimulating, but 81 ppm were always toxic. It was impossible to deprive the controls entirely of selenium, since they received an initial supply from the seeds, but they made slow growth in comparison with that of the plants which received selenium in the culture solution. These experiments showed that selenium is a stimulating and possibly essential mineral element for the development of the indicator plants.

A totally different response was obtained with several of the non-indicator species of *Astragalus*, including *Astragalus crassicarpus*, *Astragalus drummondii*, *Astragalus palans*, *Astragalus lonchocarpus*, *Astragalus carolinianus* and *Astragalus canadensis*. These species, when grown in artificial media, were not stimulated, but instead were poisoned by selenium. They were injured by one third of a part per million and killed by 9 ppm. In their response they resemble



TWO–GROOVED VETCH

Astragalus bisulcatus, ONE OF THE SELENIUM-BEARING RANGE PLANTS CAUSING HEAVY LOSSES OF CATTLE AND SHEEP. A HANDSOME PLANT WITH VIOLET FLOWERS AND TWO-GROOVED PODS.

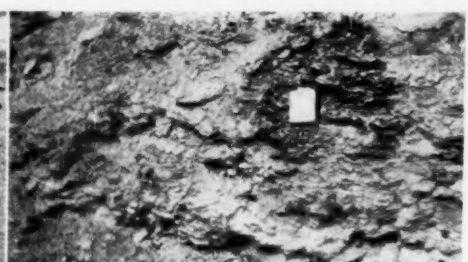
BAD WHEAT AND BAD LAND
Left: FARM PRODUCING TOXIC WHEAT ON PIERRE SHALE SOIL IN SOUTH DAKOTA. *Right:* OUTCROP OF PIERRE SHALE.

wheat, buckwheat, soybeans and tobacco. The poisoning manifests itself in plants by stunted growth followed in severe cases by death.

Chemical analyses of the plants in artificial culture brought out a marked difference in the ability of the two types of *Astragalus* to accumulate selenium. *Astragalus racemosus* was able to store more than 4,000 ppm without dwarfing or other injury. *Astragalus crassicarpus*, in contrast, resembled wheat and other crop plants in being able to accumulate only relatively small quantities.

The greenhouse tests of growth in artificial media have confirmed field observations in showing a physiological differentiation of *Astragalus* species into two groups: those which require selenium for their development and so serve as indicators of seleniferous soil areas, and those which do not utilize selenium. Incidentally, response to selenium is useful as a physiological character for classifying *Astragalus* species, and it provides a new approach to the construction of an evolutionary tree of the genus.

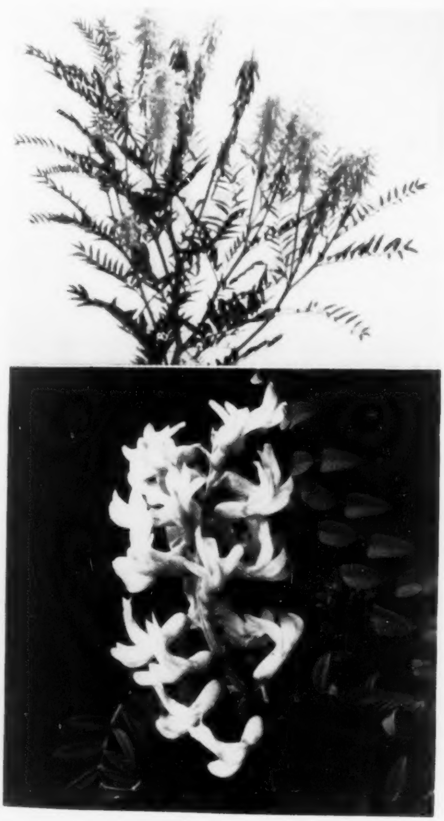
The non-indicator species of *Astragalus* occur on both non-seleniferous and seleniferous soils, since they are neither benefited by selenium nor poisoned by the low concentrations available in natural soils. Even when growing on seleniferous shales and in proximity to the selenium-accumulating species, they are free from selenium or contain mere traces. No clue has yet been found in attempting to explain these striking differences in the ability of closely related species to absorb and accumulate selenium.

SELENIFEROUS NIOBRARA SHALE IN WYOMING

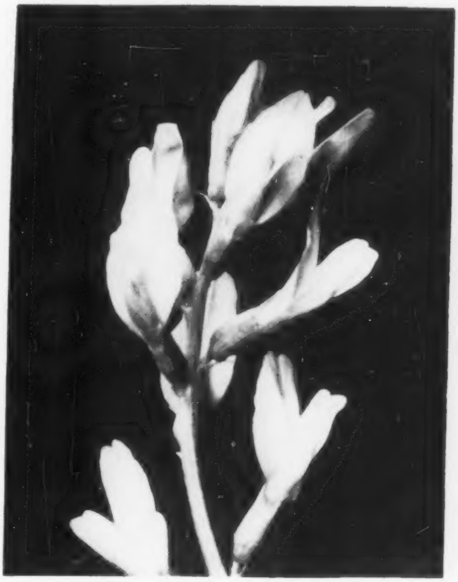
Selenium Converters

Native selenium indicator plants, according to O. A. Beath and his associates, play a very important part as selenium converters and soil contaminators. *Astragalus bisulcatus* and other selenium-accumulating plants absorb selenium from virgin shale soils, convert it into water-soluble forms, and return it to the soil in forms available for absorption by other types of plants, including farm crops. The organic selenium compounds of the converter plants may be extracted freely with water. Through the decay of foliage, seeds and roots of these plants, the selenium goes back to the soil in forms readily available to any type of plant. In some toxic regions accumulation of organic selenium in the soil may have gone on through countless cycles of growth and decay of the converter plants.



A SELENIUM INDICATOR PLANT

Astragalus racemosus. IT GROWS ONLY ON SELENIFEROUS SOILS AND IS DISTRIBUTED FROM NORTH DAKOTA AND WYOMING TO TEXAS AND NEW MEXICO.



ASTRAGALUS BEATHII

A SELENIUM INDICATOR ABUNDANT NEAR THE GRAND CANYON, ARIZONA.

Plot experiments by O. A. Beath have shown that water extracts of *Astragalus bisulcatus*, if mixed with crude undecomposed Niobrara shale, enable barley, wheat and other farm crops to absorb toxic amounts of selenium, whereas these crops when grown on the same shale without the addition of the extract can absorb only traces of the poison. Most farm crops are almost certain to absorb dangerous quantities of selenium if sown on soil prepared by plowing under a heavy stand of native selenium-bearing plants.

Native grasses and other forage plants, when growing in proximity to selenium-bearing range plants, absorb enough selenium to make them poisonous to animals, but the same species of plants are essentially selenium-free when grown on uncontaminated shales.

In most farming areas the cultivated crops absorb little or no selenium, even though the soils contain some of the poison. The absorption of toxic amounts by farm crops is perhaps always dependent upon previous activity of converter plants.

Enrichment of the soil in available selenium progresses in a vicious spiral. Many of the most toxic farms are periodically abandoned, and while uncultivated they are overrun by converters that make them even worse than before.

Among the common fodders, alfalfa is noteworthy because it rarely, if ever, produces selenium poisoning of livestock. Chemical analyses of alfalfa cultivated in selenium-bearing shales show only traces of the poison. Even when alfalfa is grown on a plot that has previously borne a dense stand of seleniferous *Astragalus*, the crop usually is unable to absorb toxic amounts of selenium.

Possibility of Human Injury

The selenium problem is of special importance because of the possibility of human injury from the consumption of grains, vegetables, eggs, dairy products and meats from affected areas. Extensive investigations into the poisoning of animals have already been made, but the research required on human phases of the problem seems barely to have been touched.

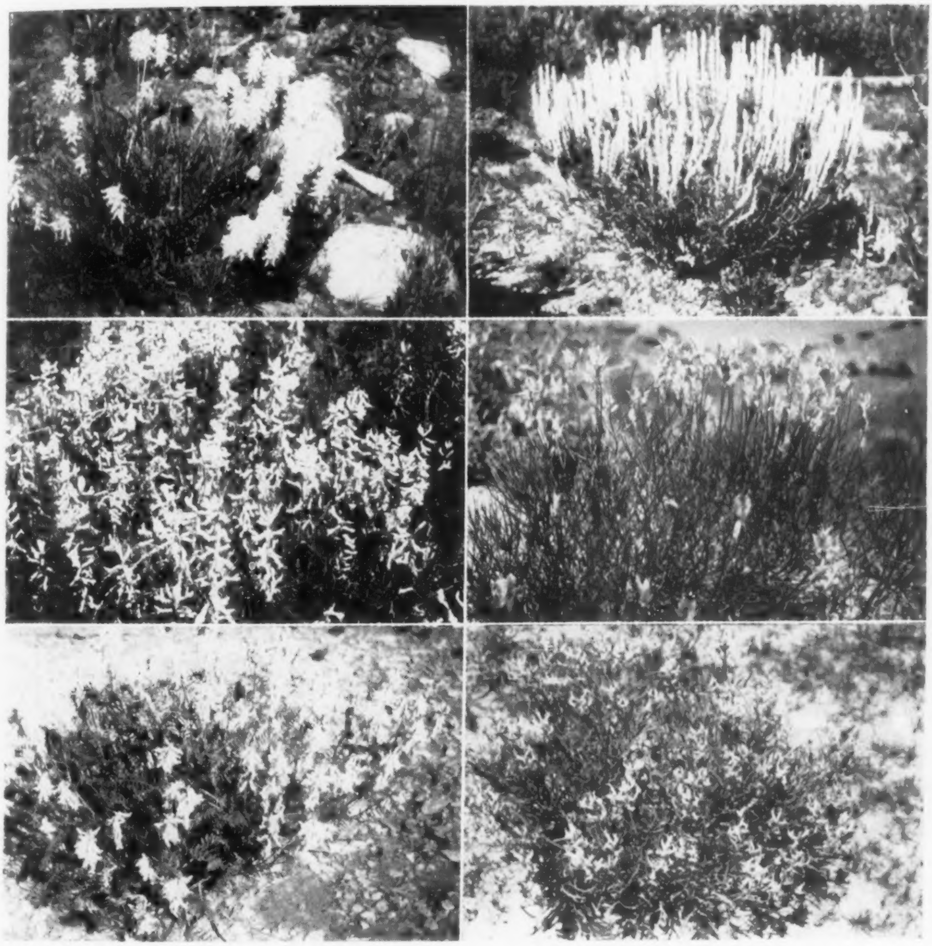
In 1936 M. I. Smith, of the U. S. Public Health Service, made a preliminary survey of some of the rural population in parts of South Dakota, Wyoming and Nebraska to investigate indications of selenium poisoning through the consumption of locally produced foods. A series of 111 families was studied for clinical evidence. Among 127 specimens of urine representing subjects from 90 families, 92 per cent. were positive for selenium and contained from 0.02 to 1.33 parts per million.

A more detailed study was later made of a selected group comprising 50 rural families in Lyman, Tripp and Gregory counties of South Dakota and the adjoining Boyd county of Nebraska. This region had been found in the earlier survey to be highly seleniferous—as shown by the selenium content of the soil, the prevalence of alkali disease in livestock and the relatively high concentration of selenium in the human urine. The selenium content of 100 urine specimens ranged from 0.2 to 1.98 parts per million. There was little variation in the urinary concentration of selenium for the members of the same family or for the same individual at different times. This indicates that the excretion of selenium is a fairly reliable index of the hazard to which man is exposed. Aside from high incidence of symptoms pointing to gastric or intestinal disorder, neuritis and a few cases of apparent liver ailment, no other evidence of ill health was seen that could be ascribed to selenium with any degree of certainty. Many vague symptoms of ill health and some of a more serious nature were observed, but none was sufficiently characteristic to be ascribed definitely to the ingestion of selenium.

TABLE 1

Maximum Selenium Content of Foods from Farms

	Parts per million of selenium
Wheat	30.0
Corn	30.0
Rye	25.0
Onions	17.8
Barley	17.0
Oats	15.0
Asparagus	11.0
Eggs	9.1
Meats	8.0
Rutabagas	6.0
Cabbage	4.5
Peas and beans	2.0
Carrots	1.3
Milk	1.3
Tomatoes	1.2
Beets	1.2
Water	1.0
Bread	1.0
Potatoes	0.9
Cucumbers	0.6

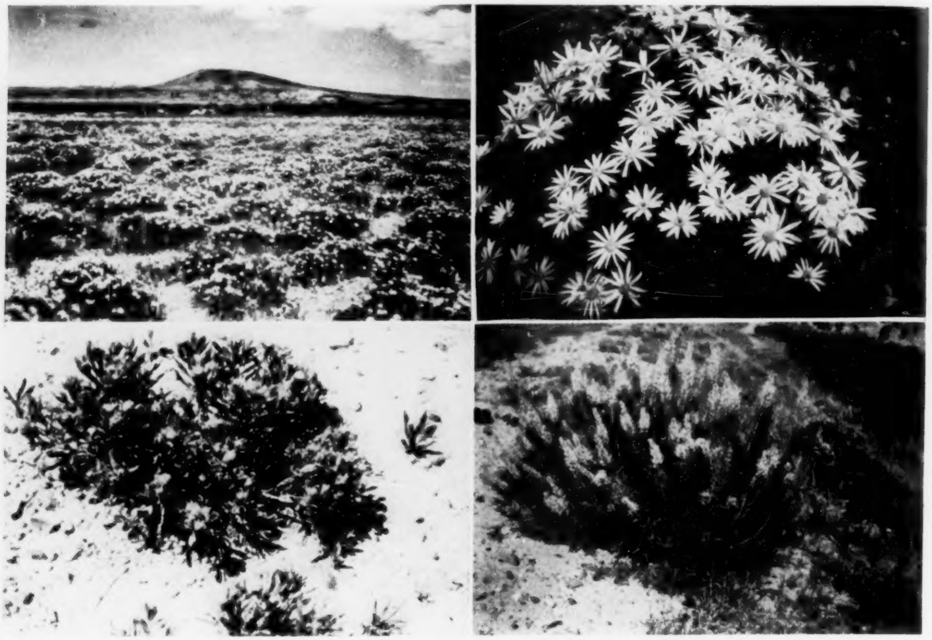


SOME SPECIES OF *ASTRAGALUS* THAT ACCUMULATE SELENIUM
AND SERVE AS SELENIUM INDICATORS. *Top: left, Astragalus oocalycis; right, A. haydenianus. Middle: left, A. pectinatus; right, A. toanus. Bottom: left, A. pattersonii; right, A. grayi.*

In 1940 R. E. Lemley reported several cases of chronic dermatitis in South Dakota caused by the ingestion of seleniferous food. Administration of bromobenzene brought about a rapid increase in the elimination of selenium in the urine (as had previously been discovered by Moxon for selenized animals) and resulted in a marked relief of the symptoms. Bromobenzene is therefore of both diagnostic and remedial importance.

Table 1 shows the selenium contents of some foods from the seleniferous area. It is believed that a concentration of 5 parts per million in common foods, or one half a part per million in milk or water, is potentially dangerous.

Human injury might be more severe in the seriously affected areas if the inhabitants provided a larger fraction of their diet from their own produce. Few small mills exist, however, and the farmer sells his wheat and uses blended flour from Minneapolis or other distant milling centers. Relatively few vegetables are raised locally. Animal products, such as meat, eggs and milk, seem to be the most important and most constant



SELENIUM ACCUMULATORS AND INDICATORS
Upper: left and right, Xylorrhiza parryi (WOODY ASTER), WHICH, WITH ITS RELATIVES, COVERS THOUSANDS OF SQUARE MILES OF GRAZING LAND IN THE WESTERN STATES. *Lower: left, Oonopsis condensata,* A RELATIVE OF GOLDEN ROD; *right, Stanleya pinnata,* PRINCE'S PLUME.

source of selenium to which the inhabitants of affected areas are exposed. The question of the effects of selenium, in the quantities ingested, on the health of the local population has not yet been satisfactorily answered, but careful investigation may help account for some of the obscure ailments in the seleniferous areas.

Wheat is of special interest because of its use in bread and breakfast foods. The per capita consumption of wheat flour alone is about 160 pounds a year. The selenium content of 1,000 samples of wheat and wheat products from seleniferous areas was reported by K. T. Williams. The maximum content found was 30 parts per million of selenium. Only about 1 per cent. of the samples contained 10 ppm or more, and all these came from relatively small areas in South Dakota and northern Nebraska. Approximately 95 per cent. of the samples showed less than 5 ppm. During the summer of 1940 we collected 21 samples of young wheat in Montana fields in which *Astragalus pectinatus* or *Astragalus bisulcatus* was found growing. Analyses by Beath showed that the wheat samples averaged only 1.9 ppm of selenium. Only one sample contained as much as 8 ppm, and this was in a field in which *Astragalus pectinatus* had 1,890 ppm. T. Thorvaldson and L. R. Johnson examined the selenium content of 230 composite samples made up of 2,230 individual samples of wheat from Saskatchewan, where highly seleniferous *Astragali* occur and selenium poisoning of livestock is known. The maximum amount of selenium found in the wheat was 1.5 ppm, this quantity being present in 10 of the 230 composites. The average for all samples was only 0.44 ppm. The

authors consider that the bulk handling of wheat for export would prevent the selenium content from greatly exceeding this average.

No serious attempt has yet been made to estimate the danger to public health outside the selenium area. The opinion has been expressed by several writers that even though highly toxic wheat is marketed, its dilution with non-toxic wheat and the small fraction which bread constitutes of the normal diet tend perhaps to render it harmless. But in the absence of exact information, nothing is to be gained by attempting to minimize the public health aspects of the problem. All foods derived from seleniferous areas should be analyzed and their course in the markets traced. Grains and meats, especially liver and kidney, in which selenium tends to accumulate, should be examined with special care. Public health surveys should be conducted in regions where seleniferous food is consumed, and physicians should be acquainted with methods for diagnosis of incipient poisoning. The problem is not confined to the United States, for selenium has been found in wheat from Canada, Mexico, Argentina, Australia, New Zealand, South Africa, Algeria, Morocco, Spain and Bulgaria.

Considerable hazard attends the use of selenium compounds as insecticides, since there is danger from even minute quantities of this element in soils on which food products are grown. Even spray residues ordinarily considered innocuous may be made available to the plant and be accumulated in toxic amounts.

Control and Prevention

It is evident from the preceding discussion that much more research work will need to be done before adequate methods of control and prevention of selenium poisoning can be applied. The following control measures may be suggested.

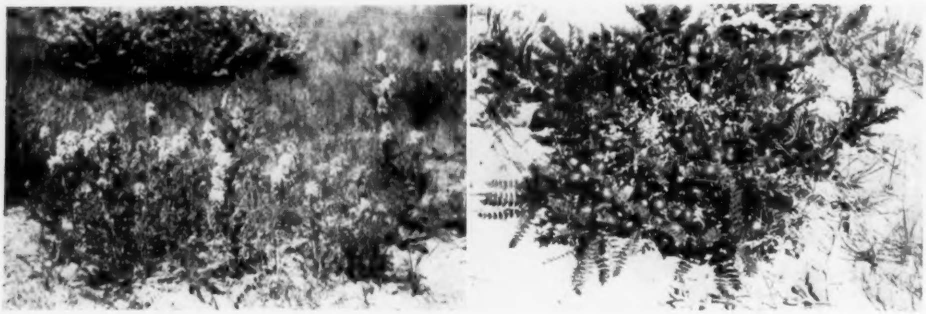
1. Seleniferous areas producing toxic vegetation should be located and mapped. Suspected areas should be carefully studied. Both the actual toxicity of the vegetation and the capacity of the soil to produce toxic vegetation need to be considered. If the native forage plants are largely grasses, the vegetation will be relatively non-toxic. But the same soil may be capable of supporting very poisonous woody aster, *Astragalus*, etc.

2. Areas known to produce toxic grain and forage should be immediately withdrawn from cultivation or grazing. Because of its reputation as a toxic area, a tract of 100,000 acres in South Dakota has already been withdrawn by the government from wheat cultivation.

3. Studies should be made of toxic limits and tolerance limits, diagnostic symptoms and remedial measures for selenium poisoning in man and animals.

4. Tolerance limits of selenium in food

OPPOSITE EFFECTS OF SELENIUM
ON TWO SPECIES OF *Astragalus*. *Above: Astragalus racemosus* STIMULATED BY SELENIUM. *Below: Astragalus crassicarpus* POISONED BY SELENIUM. SELENIUM CONCENTRATIONS IN CULTURE SOLUTIONS (*left to right*): 0, ½, 1, 3, 9 PARTS PER MILLION.



ABSORBERS AND NON-ABSORBERS OF SELENIUM IN SAME GENUS
Left: Astragalus carolinianus IN THE FOREGROUND IS UNABLE TO ABSORB SELENIUM FROM A SELENIFEROUS SOIL, WHEREAS *Astragalus bisulcatus* IN THE BACKGROUND ABSORBS ENORMOUS QUANTITIES OF SELENIUM. *Right: Astragalus crassicarpus*, ANOTHER SPECIES THAT IS INCAPABLE OF ABSORBING SELENIUM.

for man and animals should be established and enforced by government inspection. Toxic grain, vegetables and animal products should not be used for human consumption. Likewise, animals should not be allowed to feed on toxic pasturage, hay or grain.

5. Destruction of highly seleniferous native range plants and revegetation with forages which are not selenium accumulators may be practicable in some regions.

6. Over-grazing should be prevented, since scarcity of good forage tends to force animals to feed on the highly seleniferous vegetation.

7. Some forage plants, such as alfalfa, may safely be grown on mildly seleniferous soils.

8. Non-food plants, for industrial use, may be cultivated on seleniferous soils.

9. Drainage may serve to reduce the available selenium content of irrigated soils.

Other Minor Elements

The poisoning of livestock and man through the consumption of selenium absorbed by plants from minute quantities in the soil is only one phase of the broad subject of the relationship of the mineral elements to health and disease in plants, animals and man. During the past two decades we have come to realize that certain mineral elements are required in exceedingly small amounts by all living organisms. These microtrophic elements essential for life include iron, copper, manganese, zinc, iodine, boron and possibly cobalt, molybdenum, gallium and others. Like the vitamins, they are needed in infinitesimally small quantities. Yet deficiency or excess of even a single mineral element can lead to serious disease, in plants as well as in animals. Plants that have absorbed suitable quantities of these elements for healthy growth may nevertheless contain amounts that lead either to deficiency diseases or poisoning in animals that use them as food. Selenium appears to be needed by only a few plants; it is tolerated by other plants; and, as far as we know, it is toxic but never beneficial to animals or man. There is evidence that certain other elements, such as fluorine and arsenic, can have only deleterious effects. The role of the minor elements in health and disease opens a whole new field of intensely interesting research, having a vital bearing upon human welfare.

EVOLUTION OF AUSABLE CHASM

By Dr. CHARLES E. RESSER

CURATOR OF PALEONTOLOGY, U. S. NATIONAL MUSEUM

THOUSANDS of people visit Ausable Chasm in northeastern New York every year. Whether they stand on the rim and look into its depths, or climb down over the vertical walls, or walk along the trail in the chasm, or go down the swift rapids in boats, they all wonder how it came to be. The chasm is beautiful in the shadows of its depths, in its coloring, in the form of its rock ledges and in its moving waters. While the visitor is enthralled by this beauty, the question of its origin and history always crops up in his mind.

Ausable Chasm is the handiwork of the Ausable River. Its geological history tells a rather simple story and one that the visitor can read as he enjoys its beauty. Like the Grand Canyon of the Colorado, Ausable Chasm owes its origin chiefly to the cutting power of running water. No catastrophe was needed to cleave the deep gash of the chasm—merely time and water. Ausable River on its way to Lake Champlain, from the region of the higher peaks in the Adirondack Mountains, in its lower course met a happy combination of conditions which permitted the river to cut this extraordinarily beautiful canyon. None of these conditions is in itself unusual and none involves exertion of sudden great mechanical force. In fact any such event would throw down the loosely piled ledges of its walls and destroy the chasm.

WHY IS THERE AN AUSABLE CHASM?

Nearly all other streams flowing down the northern and eastern slopes of the Adirondacks also have canyons, but none is as beautiful as Ausable. We ask ourselves, Why not? The answer is that none of the other streams met the requisite elements all together. And what are these elements? First of all, there had to be a swiftly flowing river that found a sheet of flat-lying rock in its course, for vertical walls are not easily produced in folded or tilted beds, or in massive rocks. Moreover, the sheet of rock encountered had to be not only in a horizontal position, but composed of layers and blocks that could be removed in a manner to leave vertical walls. In the next place, this rock thus left by the river had to be of such a nature, both physically and chemically, that the walls should not crumble too fast. Finally, the geological history of the Chasm had to be long enough to cut the deep canyon and short enough so that time was insufficient for the weather to level down the walls to an ordinary valley profile. Fortunately the recent glacial period furnished these necessary limits to its geologic history.

There are, therefore, only four simple requirements: a swift river, flat-lying sedimentary strata for the river to cross, rock of the right sort to form the walls and limited time. None of these involves catastrophic action, nor is any one difficult to comprehend. However, when we put them all together, the geologic story of Ausable Chasm goes far back in the earth's history, and its story becomes long and intriguing.

MUCH BEAUTY IN THE CHASM PRODUCED BY THE COLUMNAR ROCK STACKS
THOSE REPRESENT THE WALLS REMAINING BETWEEN THE LATERAL SLOTS.

The Adirondack Mountains are composed of some of the oldest rocks on the earth's surface. They attract many visitors by their ruggedness, which culminates in Mt. Marcy at an altitude of 5,344 feet above sea level. Ausable River rises high on the slopes of this mountain and empties into Lake Champlain, less than 100 feet above sea level. This means that the river must fall many thousands of feet in its course. Thus our first necessary condition, a swift stream, is met. As we go further in our description we will see that the river did not have such an easy time, but was pushed about by the ice of the Pleistocene Glacial Period.

The second condition has a far more complicated history. To-day the Adirondacks are a mountainous mass of ancient crystalline rocks standing above the surrounding valleys and lowlands. Hundreds of millions of years ago these same ancient rocks held a relatively elevated position. Of course, no geologist was there to see what happened, and the enormous length of time since elapsed naturally obscures details, yet it seems that during the Cambrian period what we now know as the Adirondack Mountains constituted a land mass surrounded by waters of the sea which had invaded the continent. Into these waters came rivers off of this island, carrying sand from the rocks exposed to the weathering. This sand was deposited in layers in the seawaters as it is to-day along all coasts. No doubt as time went on these streams and the waves along the shores gathered up enough sand to form a sheet of considerable but variable thickness all around the island. To-day we find fragments of this sheet along the northern and eastern flanks of the Adirondacks. These sediments, known as the Potsdam sandstone from the town of that name in northern New York, were deposited some 400 million years ago during the Upper Cambrian period.

The Adirondack Mountains have had a comparatively uneventful geological history, for this mass of ancient rock had a tendency to hold an elevated position through geologic time. Seemingly they formed an island during Cambrian times, and when the present elevation of New York and New England was attained they still stood above their surroundings. Their present altitude was reached by more or less vertical uplift, as in the region of the Grand Canyon and other plateaus of southwestern United States, and not by folding and buckling of strata, the process by which most mountain ranges are produced. For this reason the Potsdam sandstone never was folded, but it could not escape the vicissitudes of geological processes. These sediments have been broken by great cracks, called faults, along which blocks were displaced. They have been eroded by streams and scoured by glaciers, until to-day, as shown by the geological map of New York, the Potsdam and overlying strata cover only scattered patches along the flanks of the Adirondacks.

Thus was created the second necessary condition, a flat-lying sandstone sheet, in which a swift river could cut a box canyon. But already we see why we say a happy combination of conditions resulted in the formation of Ausable Chasm. Not only must there be the swift river and the sheet of sandstone, but somehow the stream's course must be directed across one of these small sandstone remnants.

If there is a swift river and a sheet of horizontal sedimentary beds with the river flowing in the right place, the next condition is that the rock must be of the proper sort to stand in vertical walls. This involves physical strength and chemical stability under the never ceasing attack of the weather.

The Potsdam sandstone in Ausable Chasm ranges in texture from a soft,

RAINBOW FALLS AT UPPER EROSION LEVEL AND HEAD OF CHASM
POWER USES CAUSE FALLS TO BE DRY EXCEPT AFTER RAINS.

friable sandstone to a hard, dense quartzite. Most of the rock consists of clean washed quartz sand cemented by silica, but some beds contain a little clay and other impurities, and at a few places the cement is calcareous. The photographs show how ledges are strong enough to support themselves where they project many feet from the walls. Except in the rare spots where calcareous cement was rather abundant, none of the constituents of this rock yield readily to chemical action. And so our third condition is met.

Now, we must find an agency to limit the life of Ausable Chasm, which is a young valley in the terminology of the geologist. Valleys have distinct characteristics at the various stages of their life, and in the course of time must disappear as erosion levels off the land. If time is too short the stream can cut only a short canyon; if too long ordinary weathering agencies will be able to break down the walls, giving us a valley with the normal V-shaped profile. In the case of Ausable Chasm this regulation of time was supplied by the episodes of the recent glacial period.

The Adirondacks were well within the field of action of the great ice sheets that moved south from Canada. Coming down on the region from the north and northeast, the ice sheet had its advance opposed by the elevated mass of the Adirondacks and was forced aside by it into two great ice streams, which worked their way around the region. The one advanced up the St. Lawrence valley, then turned south along the west side of the Adirondacks. The other turned south through the Champlain valley. As the ice increased in thickness, it encroached more and more on the flanks of the Adirondacks, till finally it overswept the whole and persisted in this condition for a long time. While the basal currents of the ice continued to be controlled by the topography, the main mass swept over the whole region in a general south-

westerly direction. Changing conditions ultimately brought about recession of the ice. The thickness was least over the highlands, and the ice first disappeared there, leaving the two great ice currents sweeping round the region, as they did during the advance.

The final disappearance of the ice left the topography modified both by glacial wear and glacial deposits, and stream courses more or less modified. With such treatment after the millions of years of normal stream action, it is a wonder that any remnants of the Potsdam sandstone sheet remain to indicate its former presence and extent.

The whole region apparently was depressed while the ice was present and for a time after the ice had disappeared. At the height of the depression sea waters invaded the valleys of the region, penetrating Ausable River above the chasm to about Keeseville. This rather complicated series of events in the later history of the region gave rise to the terraced topography one may see from an eminence. After this the whole region was elevated. This elevation amounted to about 800 feet at the north end of Lake Champlain, decreasing to zero south of New York City.

There possibly was an Ausable River before the ice covered the region, but if so it took another course. It was only after the ice sheet melted that the river began to flow in its present channel, and began the work of cutting Ausable Chasm. Because this event happened not very long ago, geologically speaking, time has been insufficient to break down or even seriously deface the Chasm walls. And so our fourth condition is met, and we may enjoy the great beauty of Ausable Chasm.

The Cutting of the Canyon

When the ice melted and Ausable River began to flow in its present course,

LOOKING DOWN FROM RAINBOW FALLS

SHOWS HIGHWAY BRIDGE AND UPPER STRETCH OF THE CHASM. SEVERAL SMALL FALLS REPRESENT OTHER EROSION LEVELS THAT HAVE NOT YET CUT BACK TO RAINBOW FALLS.

DAM AND FLAT ROCKS OF CHASM ABOVE RAINBOW FALLS

THE DAM IS FOR POWER PURPOSES AND PREVENTS UPSTREAM MOVEMENT OF THE FALLS. WHENEVER THE RIVER LOOSENS A BLOCK WHICH THREATENS THE SAFETY OF THE DAM THE POWER COMPANY FILLS IN THE SPACE WITH CONCRETE; THUS IT INTERFERES WITH NATURE'S PROCESSES.

most of the sandstone sheet near Keeseville was intact, with the river flowing over it. Previously ice had filled Lake Champlain, and as it scraped its way southward cut back the spurs and piled up the deposits in the coves. In this manner terraces were created along the lake shore over which Ausable River flowed. Its lower course lay over some of these glacial débris, into which it rapidly sank its channel. To-day a steep-sided, V-shaped channel extends upstream through these deposits from the delta at Lake Champlain to the lower end of Ausable Chasm.

Rivers flowing down steep slopes do not usually cut their channels down evenly, but work hardest at the base of the slope. This causes rapids or falls which move upstream, leaving behind them vertical side walls. However, a stream seldom puts all its drop into one falls, but because of varying hardness, placement of cracks or other accidental causes more than one falls and rapids develop. Each of the erosion levels thus developed moves upstream, more or less maintaining its respective height. In this manner Ausable Chasm was cut back from the lower edge of the Potsdam sandstone sheet to its present length. As long as the power dam remains above Rainbow Falls at the head of the canyon, no further headward erosion will be permitted. Meanwhile the secondary levels, the falls and rapids downstream, will continue their upstream movement until they join and increase the height of Rainbow Falls.

Let us now look at the detailed process of cutting. How the falls and rapids move upstream and leave behind them vertical side walls has already been explained, but the manner in which the rock is removed from the channel is still to be described.

Ausable River rises to considerable heights in floods, when large blocks of rock are rolled along in the channel. But even in the flood stages this river carries comparatively little sand and other débris. At normal stages the water is clear, a fact due to the presence of lakes in the upper course of Ausable River, which trap the sediments washed off the mountain slopes. As a consequence Ausable River does little scouring of rocks, the commonest manner in which streams cut their channels. So we must look for another means as the chief agency in cutting its channel. Before describing that process reference needs be made to the preparation of the sandstone for removal.

The Potsdam sandstone is bedded in thin and moderately thin layers. Variation in texture, quantity and kind of cement, and impurities present, permit the weather to loosen the layers along the bedding plane. The tectonic forces which affected the region put twisting stresses on the sandstone layers and developed several joint systems. Everyone has seen glass in a door or window which has been subjected to twisting strain and has observed how cracks are developed. The cracks follow a system, usually two roughly parallel sets at right angles to each other. If the glass were a cube instead of a sheet, more than two sets of cracks would be apt to develop. Such sets of cracks in rocks are called joints. In Ausable Chasm the bedded sandstone is jointed so that almost everywhere the rock can be taken out in more or less cubical or rectangular blocks.

Frost and other agencies have loosened many of these blocks which lie about everywhere, except in the channel swept by flood waters. Few of the blocks within reach of the water have corners or edges worn off, hence we know there has been little scour. Most of the channel cutting is done by removal of block after block. This removal appears to be done only in part by the force of flowing water, but seems to be mainly a plucking process in which the water is assisted by ice. Ice freezes in the quiet reaches, and where the water passes over rapids the ice forms on the rocks. Late in winter ice forms great masses at these spots, and when the spring freshets come suddenly, the augmented flow of the stream picks up ice, rocks and all and carries them down toward the lake. Thus the cutting of the gorge goes on year after year, much faster than the clear water could cut its channel by scour or than the chemically stable sandstone walls would crumble under the influence of the weather. The rapidity of this process formed a long chasm since the ice age.

At some places, particularly in the Long Gallery and the Grand Flume, the Chasm walls stand particularly straight and smooth. This is due to the presence of master joints. Most of the joints run through one or several beds of sandstone.

ELEPHANT'S HEAD
A COLUMN THAT IS RESTRICTED AT BOTTOM DUE TO OBLIQUE VERTICAL JOINTS.

UPPER END OF DEVILS OVEN FAULT
A SHORT DISTANCE DOWNSTREAM FROM THE RIGHT-ANGLE TURN BELOW HORSESHOE FALLS, WHERE THE STREAM ENTERS THE FAULT WHICH DETERMINES ITS COURSE TO DEVILS OVEN. NOTE SLIGHT OVERLAP OF STRATA ALONG FAULT LINE.

Occasionally a joint will extend across many beds, in fact at places the master joints run through several hundred feet of beds. When the river found one of these, it cut down rapidly and the resulting wall was so smooth that the weather had less chance to work on it.

Travelers frequently ask the question: "How many years were required to cut Ausable Chasm?" Geologists are not greatly interested, nor can they readily measure geological events in terms of years. They date earth history according to relationship of one event to another. For example, if there are two layers of sedimentary rock in normal position, the upper one is younger than the lower. Whether ten years or several thousand years are required to deposit either of the beds can not be determined readily, and it really makes little difference for geological understanding, as the order of happening serves for most purposes.

Various attempts to arrive at some estimate of geological time in terms of years have been made. Most of the earlier attempts were unsatisfactory, but for this purpose it has been found that the disintegration of radium minerals can be relied on to a certain extent. For the more recent events, particularly those associated with the rather late ice age, other means are used. A method that gives a more or less definite determination of age in years is the counting of varves. Varves are fine layers of sediment in certain types of glacial deposits which are thought to represent the differing detritus of the winter and summer months, the latter having much more plant material, because of the growth of plants in the warm season. Another method employed to determine the years since the last glacial ice retreated is to estimate the time needed for Niagara

THE POST OFFICE
SOFT LAYERS OF ROCK PRODUCED BY LEACHING OF CALCAREOUS CEMENT. THESE LAYERS CONTAIN FOSSILS. TOURISTS PIN MESSAGES HERE.

Falls to cut back from Queenston to its present position, for it seems that the Niagara flowed in its present course only after the ice melted. Ausable Chasm is also postglacial and therefore comparable in age to Niagara gorge.

Estimates of the age of the Niagara gorge vary. Some put the time as short as 15,000 years, while others think it exceeds 35,000 years. It may thus be assumed that the Ausable River took at least 15,000 or more years to cut its chasm.

It will be observed that Ausable Chasm is not straight. From Rainbow Falls to the angle below the highway bridge the river follows a northwest course. It then turns nearly at right angles to a northeast course as far as Devils Oven. From there it holds a fairly straight course to the Pool, where, it again follows the northwest course parallel with the sector below Rainbow Falls. Another right angle turn puts the river back on the

DOWNSTREAM FROM HELL GATE

BLOCK AT LEFT HAS SLID DOWN AND AWAY FROM WALLS ALONG OBLIQUE JOINT. THE BEAUTIFUL AND HARDY FERNS GROW IN THE CREVICES BETWEEN THE BEDS OF ROCK. IMMEDIATELY BELOW DEVILS OVEN, WHERE THE STREAM LEAVES THE DEVILS OVEN FAULT.

DOWNSTREAM FROM DEVILS OVEN

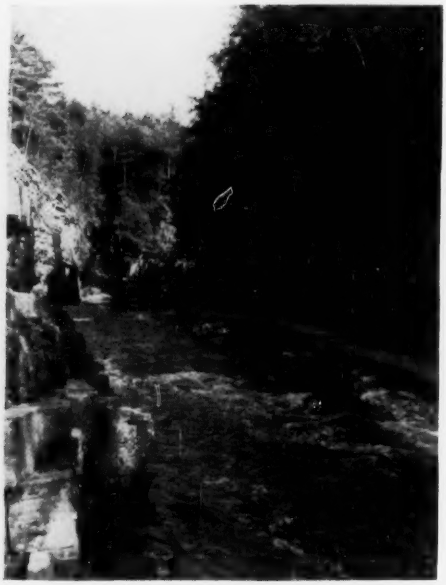
BETWEEN STEEP WALLS OF A CHASM CUT THROUGH MANY LAYERS OF ROCK BY RUNNING WATER ALONG THE LINE OF MASTER JOINTS.

northeast course again, and finally it swings back to its general line. Thus there are two more or less parallel sectors in both the northwest and northeast directions. These are due to cross faults.

A fault is a plane along which one portion of a rock mass has slipped with respect to its neighbor. In this manner it differs from a joint. Because there was movement, a fault must extend through more beds than even the greatest master joint, and consequently has more influence on erosional process. Thus the smoothness and straightness of the walls at many places is determined by the master joints, but the very course of the stream was affected by the faults.

A Walk through the Chasm

We have seen why Ausable Chasm came to be, and how it was cut by the



SHOOTING THE RAPIDS

ONE OF THE EROSION LEVELS MOVING UPSTREAM. CONCRETE WALL BUILT TO DEEPEN WATER FOR BOATS WHICH GIVE TOURISTS THE EXCITEMENT OF SHOOTING THE RAPIDS.

Ausable River. Now it will be profitable to go with the visitor through the Chasm by trail and boat and read the simple lessons in geological history clearly portrayed in the walls and channel.

As the visitor goes down the steps at the entrance, the length of the stairs emphasizes the depth of the Chasm, and the verticality of its walls. To his left at the foot of the stairs is Rainbow Falls, the highest in the Chasm. If the visitor climbs on the ledges, which are bare except at high water, he will see fine examples of ripple marks, suncracks and trails. These can, of course, be seen at other places as he walks through the Chasm. The ripples were made by the waters of the Cambrian Sea in the sand as it was deposited, telling us of waves long ago. On the other hand, the suncracks show us that at times the bottom was laid bare to the sun long enough for the sand to dry out and shrink.

Two sorts of trails occur on the same surfaces. There is the broad trail known as *Climatichnites*, a name derived from its ladder-like appearance. The other is *Protichnites*, which consists of a thin line between small impressions, just as if some animal with many legs walked over the sea bottom and dragged a long narrow tail behind. What made these trails is an unsolved puzzle.

As the visitor passes under the highway bridge he comes to the Horseshoe Falls, the second of the erosion levels moving upstream. Beyond that he approaches a sharp right-hand turn of the river. If he looks across the stream at the turn, he will see that the strata are disturbed by a break along which there was some slipping. This is the western end of the Devils Oven fault, the line of which determines the stream course to

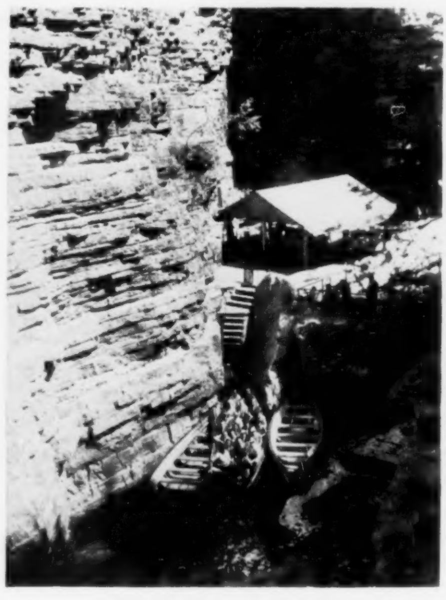


TABLE ROCK

BLOCKS DROPPED FROM RIGHT WALL MAKE CONVENIENT LANDING FOR BOATS. SINCE FLOOD WATERS RISE OVER 40 FEET, THE SHED MUST BE LIFTED ABOVE THEIR REACH. SLOTS PARALLEL TO RIVER REPRESENT OTHER CHANNELS FORMERLY USED WHEN RIVER WAS AT HIGHER LEVELS.

the Devils Oven. One of the first things noted below the turn is Pulpit Rock, and a little further along the Elephants Head. These are prominences left between deep slots cut back into the side walls.

The prominences which add so much to the beauty of the Chasm need no explanation, but the reentrants do. Why should these narrow, parallel-sided slots be cut back into the Chasm walls is a question often asked. Their straight sides naturally conform to master joints, the spacing of which determines their respective widths. Examination of the rock in these recesses invariably shows more thorough weathering than the same layers have suffered on either side. Due to this intensified weathering, the rock of the slot more readily falls down, and the stream carries away the débris. Examination of the surface above the Chasm shows that slight depressions concentrate rainwater at these points, and so we see that the recesses result merely from ordinary processes, that the local intensification is merely that which happens everywhere.

LIGHT EFFECTS IN NARROW FLUME
THE OPTICAL ILLUSION OF A SLOPING WATER SURFACE CAUSED BY THE SLIGHT DIP OF THE ROCKS, AND THE QUIET WATER, IS ESPECIALLY NOTICEABLE LOOKING UPSTREAM.

DEPARTURE FROM THE FLUME
THE NARROWEST PART OF THE CHASM. ITS HIGH STRAIGHT WALLS ARE DUE TO MASTER JOINTS. SLIGHT DIP OF ROCKS PRODUCES OPTICAL ILLUSION OF WATER FLOWING UP HILL, TO THOSE IN BOATS. THE WATER IS ABOUT 60 FEET DEEP AT LOW STAGE, ACCOUNTING FOR LACK OF CURRENT.

One of the most interesting features of the Chasm is the Devils Oven, a cave high above ordinary water level, excavated by the surge of flood waters. Here the river makes a sharp bend to the left which the flood waters have difficulty of turning. Even at that no such deep reentrant and cave would have been cut, were it not for the fact that the fault, along which the river had been flowing from the right turn below Horseshoe Falls, weakened the rock at this spot. Movement along the Devils Oven fault crushed the rock in a zone nearly forty feet wide, and next to the chief plane of movement ground

ENTERING "THE POOL" AT THE END OF THE BOAT RIDE THROUGH AUSABLE CHASM

the sandstone to powder. Ground water seeping into the rock along the fault further softened and rotted the ground-up material until it has become clay. And so the river finds an ideal spot to gouge out a cave.

No doubt some visitors wonder why the river did not continue to follow the fault in a northeasterly direction to the edge of the Potsdam sandstone block, and there fall into the lake. This question emphasizes the method of cutting the canyon, for we must not forget that this took place by falls and rapids moving upstream in an already established channel.

Across the river from the Devils Oven is another interesting feature, a large block of rock that has slid down and moved away from the walls for several feet. Examination of the block, to which one end of the foot-bridge is attached and over which the trail runs, shows that an oblique joint permitted this block to settle down into a space undercut by the river. Ferns which have found a foothold in the crevices cut along the bedding planes add greatly to the beauty of this portion of the chasm.

A short distance below the Devils Oven the visitor comes to another interesting feature, several times repeated in the Chasm. Near the water level is the Punch Bowl, a portion of a round, well-shaped hole, the outer side removed by the river. A hundred feet or so farther along the trail, which here follows a ledge high above the river, Jacobs Well is another such hole, high and dry, far above the present river level. Both of these, and others elsewhere, are the geologic feature called potholes. These holes are bored into the stream bottom by stones whirled about in an eddy.

The Long Gallery owes its long straight course and high vertical walls to the presence of master joints. Great beauty is added by Jacobs Ladder, Mystic Gorge, Hydes Cave, the Cathedral and Column Rocks, names applied to conspicuous reentrants or the columns remaining between them.

At the "Postoffice" visitors often wonder about the softness of the rock which permits them to pin cards and notes to it. Also the numerous small cavities attract attention. The latter are due to the presence of mud flakes in the original sediments that the weather finds easier to remove than the sandstone. On the other hand, the softness of the "Postoffice" layer, in a recess beneath a heavy overhanging ledge, is due to the unusually large calcareous content in the cement, which leaches out, leaving a soft sand. The "Postoffice" layer attracts the attention of geologists for another reason. They find fossils in it. Whether the fossils are there because lime deposits made the ancient sea bottom a favorable place to live, or whether the limy cement resulted from the presence of animals is a question one might debate at length.

From the Cathedral to the Pool the river flows along a nearly straight line, and fewer breaks occur in the walls. But about midway along this stretch a pronounced interruption occurs on the eastern side of the stream. Large slabs, dislodged from the walls are piled here to form Table Rock from which the boat leaves for the trip through the remainder of the Chasm. Here a thin trickle of water flows into the canyon from springs some distance above the river, and the constant wetting has rotted the sandstone, producing broken slopes. Besides this several sharp slots extend into the walls of this embayment. Contrary to most occurrences they are parallel and not at right angles to the stream. Advantage is taken of one to build a stairway, whereby the visitor may ascend to the top. If he does, he will be surprised to find in the forest nearby a dry canyon

TILTED STRATA IN UPPER BLOCK
AT KEESEVILLE. THE CHASM HAS NOT BEEN CUT THAT FAR UP STREAM.

about forty feet deep, which parallels the Chasm. A little investigation shows that at one stage the Ausable River had at least two parallel channels. No doubt, joints favored one more than the other, so that its channel became the deeper, and thus drew the larger quantity of water, thereby becoming the present channel.

The first part of the boat trip is through the Grand Flume, a narrow reach of the Chasm in which the water flows silently and deep. At some places the width is hardly a boat-length, but the river has a depth of many feet. The Flume's high smooth walls are due to evenly spaced master joints. An interesting optical illusion in the Flume always interests the visitor. Here the water is quiet and, of course, level, but the rocks dip slightly, giving the optical effect of a sloping water surface. This is particularly noticeable if one looks back upstream from a boat.

Below the Pool the boat traverses rapids, an erosion level that has not formed a falls, due to somewhat irregular bedding. At the Whirlpool Basin the stream encounters the Whirlpool fault and the stream turns into a northeasterly course and follows it. The final erosion level is the rapids of that stretch. This fault parallels the Devils Oven fault, and the off-set strata may be seen at its lower end. Advantage is taken of the broken ledges near the fault for the boat landing from which the visitor climbs to the top of the Chasm walls, over a series of natural steps.

A short distance below this point the stream leaves the sheet of Potsdam sandstone and flows through glacial drift to the delta on the shores of Lake Champlain. Due to the unconsolidated nature of the drift, the valley has a normal V-shape below this point.

Ausable Chasm satisfies the aesthetic sense of the visitor. In providing this beauty spot for man's enjoyment, nature merely used the quiet, orderly, everyday processes at its command. No spectacular catastrophic method was employed. Beautiful Ausable River systematically and patiently removes the sandstone block by block, and then flowering plants, trees and ferns assist the weather in beautifying the walls.

THE EPIC OF YELLOW FEVER[1]

By Dr. T. D. A. COCKERELL

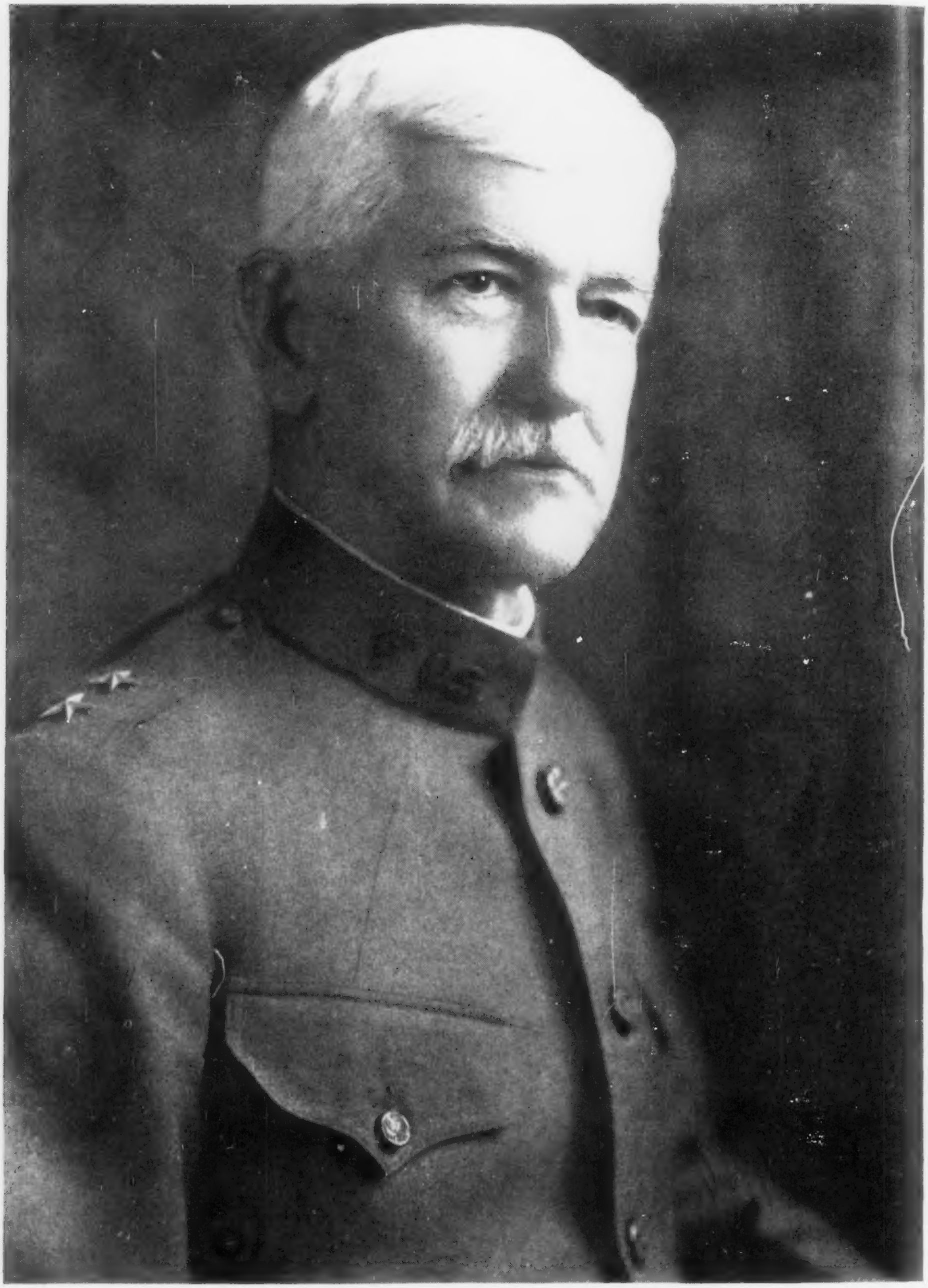
EMERITUS PROFESSOR OF ZOOLOGY, UNIVERSITY OF COLORADO

IGNORANCE begets fear, and fear has a numerous progeny of cruelty, crime and despair. Human progress, during the past century, has been marked by the conquest of fear, resulting from increasing knowledge of nature, and of the ways in which it is possible to control or combat the evils which beset us. It is an extraordinary thing, that the work of a few hundred men, within the lifetime of the present writer, has saved the lives of millions of people, and by providing the possibilities of life has made possible the existence of other millions. While doing this, it has raised the standard of living, and reduced the incidence of disease, so that life, at least in respect to these matters, has been better worth living than ever before. Of the dread trio, war, pestilence and famine, the second and third are rapidly retreating, only the first remaining unconquered. When we understand the human mind as the scientific worker understands disease, perhaps we may conquer its pathological manifestations, and attain sanity, physical health and prosperity, and with these the happiness we all desire.

It is one thing to attain knowledge, and another to diffuse it among the people. Even scientific men are often slow to see the new light, and in spite of all our schools, the public has little understanding of scientific progress. It is therefore of the utmost importance to realize the unique qualities of our age, and show them in their historical setting, a drama of extraordinary interest to every intelligent person, if presented so that it can be understood. In such ways we may dispose the people to accept and adopt the good gifts of science, and by their support make other gifts possible in the future.

Robin Lampson, of the University of California, had written a book on the gold-rush of the forty-niners, in which he described the tragic events of the journey across the Isthmus of Panama. Lampson's mother, then one year old, so crossed the Isthmus in the arms of her mother, who rode a mule. This story called Lampson's attention to the awful menace of yellow fever, as it existed in those days, and led to the writing of another book, just published, having this disease as its central theme. On the title page this is described as "A Novel in Cadence," but such a description is perhaps rather misleading. The book does indeed deal with the life of William Gorgas, as it might be treated in a novel, if he had never existed; but as matter of fact it is a biography, minutely accurate in its details, based on years of careful work, with the cooperation of numerous persons who knew Gorgas and were present when many of the events related occurred. I presume that no one will ever again go to all this trouble, and a little later it will be impossible to get the assistance of contemporaries as Lampson got it. There is a brief introduction "Concerning Debts and Sources," in which the principal contributors of information are cited, and the more important books read are listed; it appears that Lampson consulted no less than 2,700 issues of daily newspapers to get the local color of the times. As regards the Cadence, the book is really written in a kind of prose, broken up into lines, a sentence frequently broken in the middle by this arrangement. However,

[1] Robin Lampson, "Death Loses a Pair of Wings. The Epic of Gorgas in the Conquest of Yellow Fever." New York: Charles Scribner's Sons. 1939. 518 pp.



DR. WILLIAM C. GORGAS

GREAT ADMINISTRATIVE OFFICER WHO TRANSLATED SCIENTIFIC FINDINGS INTO PRACTICAL RESULTS, IN CONNECTION WITH YELLOW FEVER. DR. GORGAS DIED ON JULY 3, 1920.

Lampson is a poet, and it must be admitted that he has given the book a poetic quality, which lends a charm, and also gives him a license to deal with all sorts of little matters which would seem rather out of place in an ordinary prose biography. It is natural to ask, why does the book deal with the life of Gorgas, who was not the man who finally resolved the puzzle of yellow fever? Why not Finlay, or Reed, Carroll, Lazear and Agramonte? The answer is obvious; the story of Gorgas is, or includes, the story of yellow fever; and if Gorgas did not discover the mode of transmission, he was at any rate the great administrative officer who translated the scientific findings into practical results, and thus had a brilliant and ever memorable part in the whole achievement. Born in Alabama, Gorgas was a son of the South; his father was a soldier in the Confederate army. William Gorgas grew up with an intense ambition to join the army, and his disappointment was tragic when he was refused admittance to the Military Academy at West Point. He then took up the study of law, but it was extremely distasteful to him. It seemed for a time that he had no particular mission in life, when Dr. Bartholomew, an old friend of the family, suggested that it might be possible to enter the army as a doctor. William eagerly snatched at this solution, although he had at that time no particular scientific training or interests. Thus we find him entering Bellevue Hospital Medical College (New York) as a student. The introductory lecture, by old Dr. Austin Flint, is set forth in some detail. I quote a small part, first describing the impression made by Flint, and then giving his concluding words.

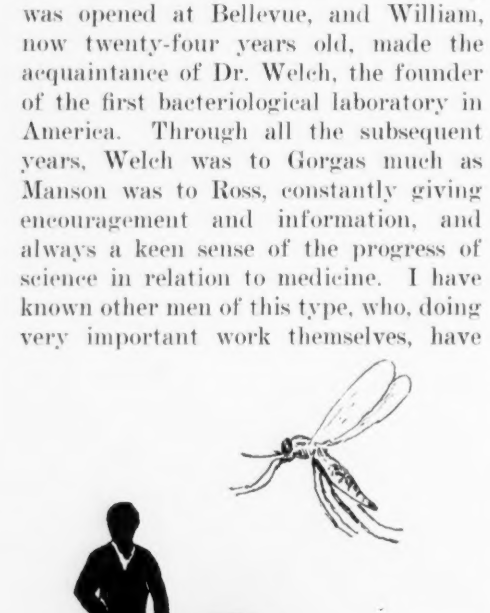
And when the substantial tall figure stepped into the room and assumed the dais,
No introduction and no praise were needed. The keen, intelligent eyes
Were already smiling; the magnificent head with its sparse gray hair, and the benignly

Courtesy of the Army Medical Museum.
DR. CARLOS J. FINLAY
WHO FOUND THE STEGOMYIA MOSQUITO WAS THE ONLY MEANS OF TRANSMITTING YELLOW FEVER.

Courtesy of Science Service.
DR. WILLIAM H. WELCH
OUTSTANDING IN THE STUDY OF YELLOW FEVER.

Beautiful face with lush silvery sideburns, announced the man and his importance
Before ever the restrained, kind mouth began speaking. Even his stand-up collar
Was eloquent
(Said Flint) "You who today are entering here are earnestly and solemnly welcomed
To join that tradition—not as sailors signing up for a voyage, and not as apprentices
Rendering eyeservice, but as bridegrooms in a permanent marriage to medical science.
I only ask you to remember that Bellevue, built by the hearts and brains
Of many great men, is greater than any individual, greater than any
Or all of us here today—and I bid you to conjoin yourselves to her greatness,
Adding the stature of your personalities to these living buildings, enriching and enabling
Your lives by Bellevue's gifts and traditions."

From such a happy beginning, William Gorgas prospered as a medical student, only hampered by his poverty. In due course of time a new laboratory was opened at Bellevue, and William, now twenty-four years old, made the acquaintance of Dr. Welch, the founder of the first bacteriological laboratory in America. Through all the subsequent years, Welch was to Gorgas much as Manson was to Ross, constantly giving encouragement and information, and always a keen sense of the progress of science in relation to medicine. I have known other men of this type, who, doing very important work themselves, have found time to correspond with and inspire those who, far from libraries and museums, might feel helpless and discouraged without this assistance. In this sense, then, Welch had a good part in the achievements of Gorgas. There is a most graphic account of the epidemic of yellow fever in Memphis, the utter terror and distress of the people.



And now, for a week, the dispatches had been a great chorus intoning, "Thousands,
More thousands falling sick; hundreds, more hundreds helplessly dying!" Pestilence
And death were the theme of the song; its refrain: "More doctors and nurses are needed,
More doctors and nurses are needed!"

Gorgas, though not yet graduated, could not resist the appeal, and with a few others, started for Memphis. He was turned back because non-immune, after hearing that his best friend, who had graduated and gone to Memphis, had died of yellow fever. Atwater's last words, as he died, were: "I have studied yellow fever all my life. I have learned everything that is known of the plague. And I die knowing nothing about it—nothing—nothing."

So Gorgas entered the army as a physician, and was stationed at various points in the South.

Welch wrote:

Bellevue appreciates my labors,
They have gone to considerable expense in adding an adjoining room to the laboratory.
I feel like a potentate with three rooms where I rule supreme with millions of microbes,
Billions of bacteria, as my subjects. We have a new microscope, too, and a splendid
Supply of beakers and test tubes, a Bunsen-type burner at each table—and three cages
Of white mice and guinea pigs and rats. . . . This has been a momentous year: in Germany,
Eberth has isolated the bacillus of typhoid; in France, Pasteur has immunized
Against chicken-cholera with cultures of attenuated virus; in America, Sternberg
Has discovered the coccus of pneumonia; an Englishman in China, Doctor Manson, has demonstrated
That mosquitoes—of all things!—are the intermediate host of elephantiasis; and a Frenchman in Algeria,
Laveran, has discovered the germs of malaria in the blood. What a decade has just ended.

What an epoch is beginning! The malignant millenniums, the ignorant centuries, are surrendering
Their dependence on guesswork and magic; and medicine must now change from sorcery to a science.

Gorgas got yellow fever himself, and after a desperate time, recovered. His first thought was:

"How wonderful it is that now, for the balance of my life, *I'm immune*. Immune!
I'll be clothed in steel. Yellow fever can't touch me—can't slam any more doors in my face."
He rested for a moment. "Now they can send me right into the fire, wherever
It's raging. I can study the disease without fear. I can open my eyes in the flames
And read what they say—if it's readable."

Eventually we come to the days in Cuba, where Gorgas was first assigned to duty on the hospital ship *Relief*, and later became the ranking sanitary officer of Havana. There is a vivid description of the inadequacy of the preparations for taking care of the American wounded, and the part played by Theodore Roosevelt, whose protest, contrary to strict army discipline, led to the return of the greater part of the army of occupation to the United States, and the consequent saving of very many lives. The American doctors classified yellow fever as a "filth" disease, and thought it could be eliminated by a general clean-up.

Dr. Carlos Finlay comes into the picture. Long before, he had become convinced that the ***Stegomyia*** mosquito was the means—the only means—of transmitting yellow fever.

"I believe that if we get Havana clean enough,"—Gorgas was now speaking fervently—
"We can free it of yellow fever."

All Finlay's native humor immediately submerged whenever yellow fever and filth were mentioned together.

"Th-th-that's where you are wrong, Doctor Gorgas,"
He said eagerly—but patiently, like a father setting right a misinformed son. "Here—

Drawing by Mrs. Bailey Willis

And here only—is the cause of yellow fever . . ."
He reached into his vest and pulled out a test tube.
"Here is the culprit. And a clean little villain she is."
He handed the glass tube
To Gorgas, who looked at it closely and remarked, to cover his embarrassment, "Why, just a—
Mosquito."
"Just the agent of transmission in yellow fever," Finlay corrected him gently.
"A black-and-white beauty, with a lyre tattooed on her back—and extremely fastidious
Habits. You may clean up the last milligram of filth in all Cuba—and still you won't touch her—
Or yellow fever."

The general impression was that Finlay was a very nice old man, and an excellent doctor, but unfortunately daft on the subject of mosquitoes.

From here the story moves swiftly to the point where Gorgas and Wood de-

Courtesy of Science Service.

DR. JESSE WILLIAM LAZEAR

ACTING ASSISTANT SURGEON IN THE UNITED STATES ARMY AND ONE OF THE YELLOW FEVER COMMISSION. HE DIED OF YELLOW FEVER CONTRACTED IN THE LINE OF DUTY WHILE SEEKING THE METHOD OF TRANSMISSION OF THE DISEASE.

cided that something more must be done, and Surgeon General Sternberg was urged to appoint a scientific commission to study yellow fever on the spot. This was done, and in spite of a strong bias against Finlay's views, the commission was gradually forced by the logic of events to turn to the mosquito, and plan experiments to prove or disprove its significance as the transmitter of the germ. The nature of these experiments, and their results, are well known; but while Lampson is here repeating an often told tale, he makes it extremely vivid and dramatic, so that the reader finds himself illustrating the book with pictures which readily form in his mind. The house full of bedding from fatal cases, in which men were confined for a long time, and yet remained perfectly healthy. The soldiers who volunteered to be bitten by infected mosquitoes, and did come down with the fever, but fortunately recovered. The yellow fever developed by Carroll and Lazear, two members of the commission, and the tragic death of Lazear. Through all these tests the undoubted truth emerged, that Finlay was perfectly right, though it had not been in his power to prove his case as it had now been proved. The practical results quickly followed. Yellow fever was exterminated in Havana, it was eliminated from Panama, permitting the construction of the canal, and it is now a rare disease in any part of the world. Recently, it has been shown that in Brazil three other species of mosquitoes can be agents in the transmission of the fever, an unexpected complication which can be dealt with because understood.

A charming account is given of the banquet in honor of Finlay, who in reply to all the complimentary speeches says:

"Gentlemen, friends,
You are listening to a blissfully happy old man.
When the battleship *Maine* was blown up,
I was ready to retire as a doctor. I felt I had completed my professional life:
To appropriate the words of the beloved Stevenson, whose national blood I share,
I had served a full lifetime 'bringing air and cheer into the sickroom, and often enough,
Though not so often as I wished, bringing healing.' And I had discovered, I knew,
An indubitable ruby of truth. The savant-jewelers of the world would give me
Neither credence nor audience. But no matter—I was not a young man any more; and from Time,
My elder brother, I had learned to be patient with eventual things. Since I knew
That my truth was immortal, secure with the centuries, I could smile at the niggardly, negligent
Decades. Neither the contempt of my contemporaries nor my death could destroy this true stone.
Now, suddenly, as I enter the twilight of retirement and the mellow rich evening of age,
Time ticks me the high noon of my triumph and pours me the sweet wine of immediate justification—
Thanks to the selfless labors of these brave and intelligent men. And, friends,
Nothing is sweeter to age than to be honored by one's fellowmen."

SCIENTIFIC PIONEERING IN THE MIDDLE WEST

By Dr. C. JUDSON HERRICK

PROFESSOR EMERITUS OF NEUROLOGY, THE UNIVERSITY OF CHICAGO

I

THE last quarter of the nineteenth century was a critical period in the history of science and especially of the biological sciences in middle North America. Here I was born, and my childhood was spent at that time on the very frontier of natural science in this continent. The thrills of exploration were daily experiences.

How close that era is to our present day is vividly illustrated by tales told to me by the late Professor John Merle Coulter toward the end of his life. As a stripling he was one of the youngest members of the Hayden Expedition of the U. S. Geological Survey when they penetrated the unknown Yellowstone region and saw with incredulous eyes the splendors of Old Faithful and the other marvels of the geyser basins. Unbelievable rumors had filtered out with the fur trappers, but the first credible accounts were brought by the Hayden party, as I learned from the lips of one of its members.

That quarter-century saw a revolution in the biological sciences whose radical character can perhaps hardly be appreciated by the present younger generation. The prime objectives and essential methods which now we take for granted were scarcely imagined seventy-five years ago. The infiltration of Darwinian conceptions of evolution had begun and the transition from the descriptive methods of field natural history and museum work to the refinements of laboratory technique and experimental research was abrupt and disturbing. In the physical and earth sciences the situation was different, for "natural philosophy," the parent of physics and chemistry, was experimental from the start and geology also came of age by slower growth. In biology the tumultuous revolution was consummated during a few decades of the lives of men still with us.

While growing up in Minneapolis during this critical period, some chapters of dramatic history were unfolding before my childish eyes under conditions which were especially favorable for its observation, as now reviewed in retrospect. My brother Clarence, ten years my senior, was a born naturalist and some of his adventures in scientific pioneering seem worthy of record if we can fit them into their natural setting of time and place. This we shall try to do, taking as our theme the annals of the Young Naturalists' Society which he, Thomas S. Roberts, Robert S. Williams and a few other sixteen-year-old boys organized in 1875. It is necessary first to survey the germination and growth of natural science in Minnesota and to picture the actual stage of development reached in that year.

II

When I was a child of nearly seven years my brother Clarence had finished his first year at the Minneapolis high school. We lived on a little farm beyond the southern outskirts of town, and I have vivid memory of a September day in 1875 when I rode in the family carryall with my father and Clarence through the city and across the river the four miles to the university. While Clarence and his father conferred in the president's office about matriculation as a subfreshman I remained outside. Some kindly body took me up the long stair-

ways to the cupola at the top of the big stone building, then new, which housed the university.

From that terrifying height we looked down almost directly into the gorge of the great River, for the campus at this point drops away in a sheer cliff of Trenton limestone, whose wealth of fossils intrigued the Young Naturalists, as they do their successors to this day. Up-stream the gorge terminates within a mile at the Falls of St. Anthony, and here spread out before our eyes was the great Government Work in process of construction. A dike of masonry 2,000 feet long supported an "apron" to protect the Falls from erosion. This expenditure of nearly a million dollars saved the Falls from imminent destruction and so saved the life of the city of Minneapolis.

During the leisurely descent from the cupola we peeked into classrooms, laboratories and the museum, filled with marvels and childish questionings. At the main entrance we rejoined the others and President Folwell put his hand upon my head and remarked with a friendly smile, "I see, my boy, that you have already been through the university, ahead of your brother."

The Mississippi River carved the destiny of the Middle West, and St. Anthony Falls made the city of Minneapolis. St. Paul, the state capital, was naturally first settled at the head of navigation in the river. Northward was unbroken wilderness whose settlement on the west side of the river was retarded by the government reservation at Ft. Snelling (established in 1819) and by treaties with the Indians. Franklin Steele located a claim on the east side of the Falls about 1837 and in 1849 the first plat of the town of St. Anthony was made, in the same year that the Territory of Minnesota was organized. The west side of the river above Ft. Snelling was ceded by the Sioux Indians to the government in 1851 and settlers began to move in, but not until 1855 were squatters' titles to land west of the Falls confirmed. In 1854 there were not more than 12 dwellings on the site of Minneapolis, though a school was opened in 1852 and in the following year there were also a church, a Masonic Lodge, an agricultural society and several mills.[1]

In 1875 the city of Minneapolis was still a frontier town. Only 25 years had elapsed since the first frame house was built west of the Falls and only 20 years since a plat of the settlement there was recorded. In 1872 the towns to the east and west of the Falls were consolidated as the city of Minneapolis, with a population of 18,316 people. The census of 1875 reported a population of 48,725 in Hennepin County, of which Minneapolis is the county seat.

During these two booming decades of expansion, frenzied speculation, panic and recovery, cultural development was not neglected. Schools came in with the first settlers. As early as 1857 there were eight organized churches. Lyceum lectures were provided and the Athenaeum laid the foundations of a great public library. In 1875 bulletins were published by the Minnesota Academy of Natural Sciences and the State Horticultural Society. After eighteen years of abortive blundering, the state university was firmly established on the east side of the Falls and a freshman class was matriculated in 1869, the first bachelors' diplomas being awarded in 1873.

Between 1860 and 1866 several reports on the mineral resources of Minnesota were published, and shortly after the opening of the state university the Geological and Natural History Survey of Minnesota was inaugurated under the direction of Professor N. H. Winchell. His first annual report to the Regents was for the year 1872. In 1875, accord-

[1] William Watts Folwell, "A History of Minnesota." Published by the Minnesota Historical Society, St. Paul. 4 vols. 1921–1930.

ingly, the survey had been in operation for only about four years, and exploration of the natural history of the state was only well started. In many fields of scientific interest the frontier began literally at the walls of the university building.

There was a nucleus of the State Museum of Natural History in the university even before the organization of the state survey. The first official recognition of the museum is in the annual report of the director of the survey for the year 1875. Its subsequent history has been systematically written and well illustrated by the present director, Dr. Roberts (my brother's boyhood chum), in commemoration of its removal in 1939 to a commodious and beautifully appointed new building.[2] From the humble beginnings of the 1870's the growth of scientific activity in this area has been rapid and fruitful, as graphically displayed in a statistical analysis of present conditions recently made by H. E. Zabel.[3]

This was the cultural environment of our community at the northwestern scientific frontier when in 1875 my six-year-old eyes were first opened to the natural world as an object of scientific interest. This scientific light dawned very gradually under the influence of my older brother, whose childish curiosity and sporting impulses were at that time suddenly canalized into a passion for science which was the dominant motivation of his subsequent life, and of mine also, though in my case maturing much later.

One of my early memories is of a letter received by the family from Clarence while he was away on a camping and collecting expedition with Tom Roberts and one or two other schoolmates. The boys were driving through the woods in a wagon and the letter included a graphic pencil sketch of a mighty tree riven by jagged forks of lightning and falling shattered across the road a few feet in front of the horse's head. As I now review the sketch in retrospect, the time schedule seems a little out of gear, for the bolt of lightning and the fallen trunk could not have been registered on his retina at the same instant; but the anachronism was not apparent to my childish mind and doubtless the thrilling incident played its part in quickening my interest in natural history. It was at about this time that Clarence and Tom dissected a whooping crane and discovered the long coils of the windpipe which provide the resonance chamber for the whoops. The observation was not new to science, but the boys did not know that and their enthusiasm about it infected the youngest as well as the older members of our family.

These boys before they were of high-school age ranged the forested hills, the swamps, the open prairies and especially the cliffs of the gorges below St. Anthony and Minnehaha Falls, all within a day's walk. These and the chains of little lakes which now embellish the city's enchanting parkways were then about as nature made them, unblemished by the hand of man. And all this was virgin soil for the naturalist.

III

Ellsworth Huntington has long been telling us of the influence of natural physical surroundings upon the patterns of growth of human cultures. What is true in the large is doubtless operative in the development of the individual man. Perhaps the Falls of St. Anthony and the other topographic features carved out of rock by the Father of Waters were equally significant agencies in shaping the growth of those alert boys

[2] Thomas S. Roberts, "Annals of the Museum of Natural History," University of Minnesota, Minneapolis, 1939.

[3] H. E. Zabel, "Minnesota's Contribution to American Men of Science." Issued by Clay-Adams Company, 44 East 23rd St., New York. 1939.

who matured within earshot of their roar and whose minds were naturally attuned to sympathetic response.

But there were other and probably more significant influences—trends of social reorganization and changes in the flow of the currents of intellectual movements of the time—which played obscure but doubtless very important parts in the stimulation and direction of interest in the case of these boys.

The cultural development of this community followed the best traditions of the colonial period. It has been pointed out that by 1850 our country exhibited four regions, each with its own characteristic social, economic and political pattern—the Northeast, the South, the Far West and the Middle West. Of the latter region James Truslow Adams says:

> The old Americanism was to be found in the Middle West, which was yet preponderantly the land of the small town, the small farmer, and the pioneer—"folks." To be sure, the lengthening shadows of eastern North and South had crept over the Valley also, but in its upper portion, what we call the Middle West to-day, the old American dream lingered because it still had foundation in the economic and social life of the people.[4]

Further on in the same work Mr. Adams emphasizes the profound changes which followed the close of the frontier period at successive stages in our great western migrations.

> [Here we witness the] forging out something new and uncommon from the common man, [something which] had come into being from the wedlock of the common man and the frontier, a marriage consummated over and over again in our history. The brood born from those who dreamed the dream grew and increased. But there would be nothing in the dream unless the new life of the common man could be made uncommon, unless out of the womb of democracy could come forth beauty of art and living that should fill the spirit with gladness and make the daily round of living something more than a perpetual subduing of the soul's wilderness for material purposes as we had subdued the wilderness of the continent.

[4] James Truslow Adams, "The Epic of America." New York. 1931.

The pioneer spirit of the upper Mississippi Valley was different from that of the Puritans and other colonists and it has played a vital part in shaping the American temper and form of government. Mr. Adams says, "For better or worse, the United States of to-day was cradled in the Mississippi Valley." The American dream of political liberty and personal freedom, with opportunity for each to enrich his life according to his own ability and interest here "could be prolonged until it became part of the very structure of the American mind."

Such were the families in which these boys grew up. The high school which they attended was probably not different from most of the others of the period in the Middle West. There was no teaching of science worthy of the name and there is no evidence that the rigid curriculum influenced them in any way in the stimulation of interest or guidance of their scientific activity. They came from good homes, but here again there was nothing in heredity or environment to serve as an activator of scientific interest. Their ancestors were plain people without academic training or traditions. They were, it is true, enterprising pioneers or they would not have settled where they did at the frontier; and to these boys, their offspring, the pioneer spirit was transmitted, though it took the quite original form of a passion for exploration of the natural world about them. The attitude of the parents, as Dr. Roberts tells me, was a "kindly tolerance and helpful assistance," but certainly this was not the source of their inspiration. Their interest in natural history was generated spontaneously; it was as natural for them as breathing.

IV

The Young Naturalists and their subsequent careers when examined in their native midwestern environment illlustrate significant features of scientific history in this country. The revolution-

ary changes in scientific outlook and method which came with almost explosive violence a long generation ago swept these young men into the turbulent current of events of which they themselves were part. The three promoters of the society responded very differently to these influences; each of them made noteworthy contributions to this historic movement, and two of them, Roberts and Williams, are still with us.

During this transitional period the far-flung exploratory adventures of the field naturalists were supplemented and too often supplanted by intensive laboratory study of minute detail. This period also saw the inception of those experimental methods whose inflorescence and fruition have been the most characteristic features of the biology of the twentieth century. . The Young Naturalists were sensitive to these changes in the spirit of the time, even though during the years of the life of their society field natural history of the old school was still the prevailing fashion. *The American Journal of Science and Arts*, founded in 1818 by Benjamin Silliman, and *The American Naturalist*, then in its ninth volume, were the chief national mediums of publication, aside from reports of the federal and state natural history surveys and proceedings of the older academies of science of the East.

The American Geological Society was founded in 1819, and out of this grew the American Association for the Advancement of Science, organized in 1848. These and other national organizations were active in all domains of scientific inquiry and especially in field surveys. Contemporary with these boys and in the prime of their scientific production were Louis Agassiz, Baird, Leidy, Asa Gray, Marsh, Cope, James Hall, Sir William Dawson, the two Winchells and many other pioneers at the frontiers of American science.

In the germination and growth of American science four sources are easily recognizable.[5] The early colonists brought with them the cultural patterns and mores of the countries from which they came, and among these British influence clearly predominated and our colleges were designed after English models. In the first decades of our republic French influence played a larger part, through such men as Franklin, Jefferson and finally Agassiz. During the second half of the nineteenth century German scholarship was preeminent and most ambitious American students completed their professional training in German universities. This influx of German trained scholars profoundly affected, not only our entire educational system, but the attitudes and interests of people in many other fields. These men initiated and controlled the organization of the graduate schools, thus transforming some of our colleges into universities which were conducted for the most part after the German pattern. The birth of true university ideals in this country may be dated approximately in 1876, with the opening of the Johns Hopkins University. Throughout the Middle West state-supported universities rapidly expanded, especially in the fields of science and industry. Contemporary with these three there was a fourth source of scientific culture—an indigenous development of naturalists on our own soil. These were the explorers, collectors and survey workers, many of whom were men with no academic training or connection.

During the organization of the universities, especially of the state universities, some of these field naturalists and survey workers were drawn into their faculties, where they served with great distinction, as their successors do to-day. Here they were given better facilities and a more stimulating environment.

[5] C. A. Kofoid, *Proceedings* of the 25th Anniversary Celebration of the Inauguration of Graduate Studies, University of Southern California Press, Los Angeles, 1936, pp. 230–235.

In many academic circles the newer disciplines of refined laboratory precision and experimental procedures were inclined to disparage the "anecdotal" methods of the field workers. In fact, some of these laboratory men did not know or care to know the species upon which they were working or realize that lack of accurate knowledge of life-histories may vitiate the most exact experiments in physiology or genetics. The history of science in the Mississippi Valley from 1875 to 1900 presents many graphic illustrations of this abrupt transition in the methodology and objectives of biological research.

Fortunately the field naturalists held their own in this unequal contest, and to-day we are coming to see more clearly the mutual interdependence of laboratory work and field studies. The naturalist is not a bug-hunter or a pebble-picker. He is a student of nature. And whether nature be observed in the open or in the breeding pen, operating table and histological laboratory, the observer is still a naturalist—or should be. The popular distinction is based on method. As Yerkes has recently said:

> Many scientists think of the naturalist as having been replaced by the experimentalist. I beg to offer contrary opinion and to maintain that the interests, objectives and methods of the two are supplementary, and neither substitutes nor alternates. For the naturalist, with minimal disturbance of organism or environment, attempts to find out about life as it is lived; while the experimentalist, with some definite problem in mind, seeks so to control the conditions of observation that solution shall be facilitated. . . . It would be ideal, as I see the situation, if in each of us biologists might be combined the interests and abilities characteristic of the best in field observer and laboratory worker.[6]

Yes, this is the ideal, and perhaps Dr. Yerkes himself approaches it as closely as any one now living.[7] The Young Naturalists were just at the threshold of the momentous changes in biological practice to which reference has just been made. Field natural history was the vogue of their time and place, and yet we can recognize in the minutes of their society now before me prophetic gleams of the impending changes. Though these high-school boys could not grasp the meaning of the eddying currents of the physical, social and especially the psychological life of their community in 1875, they evidently were not unaffected by them.

V

These radical changes in the scope and methods of the biological sciences are now established on a firm basis, the newer refinements of laboratory technique and experimental control being closely articulated with enlarged and improved field observations. This consummation of the labors of the pioneer naturalists of the nineteenth century we now enjoy. But when search is made for applications of this true scientific method in the field of education, we are discouraged by the painfully slow progress achieved by blind fumbling. Advance has been retarded here, as in most other domains of social adjustment, primarily, I believe, because the effort has been handicapped in advance by the outworn tradition that values—the key factor in the problem—are beyond the reach of science. We still have some pioneering to do in this unsettled territory.

Exceptionally gifted children are not rare and they may appear in unexpected places. Unless these exceptional endowments find opportunity for growth and expression, each after its own kind, we are wasting the most precious of our natural resources. What are we doing about this?

The native endowments of the Young Naturalists were different from those of their schoolmates. There was nothing in

[6] R. M. Yerkes, *American Naturalist*, 73: 97–112, 1939.

[7] "Robert Mearns Yerkes, Psychobiologist." Pages 381 to 407 of "A History of Psychology in Autobiography," vol. 2, 1932, edited by Carl Murchison, Clark University Press.

home or school to set them apart from the others. The school influence of 1875 tended the other way, toward regimentation with no recognition of individual differences in interest or capacity. The three promoters of the society were exceptional, not only in their passion for nature study, but even more so in their ability to educate themselves in the field of their choice. They had no guidance in this, and there was no repression.

This freedom from restraint is a vital matter, and I wonder if our schools today are doing much better than they did in 1875. Doubtless they are, but progress is hindered in curious ways that were not foreseen when the reform movements began. A generation ago the deplorably low standards of secondary education were raised by pressure from above, by forcing the high-school curriculum to conform with college entrance requirements. The desired result was promptly achieved, but at a cost of standardized mass-production in both the schools and the teachers' colleges admirably adapted to qualify the selected few to pass the standard college entrance requirements but ridiculously unfit for the five sixths of high-school pupils who do not go to college. In this connection Mr. Edison went so far as to say: "Formal education seems to paralyze curiosity. It makes the important subjects so dull as to give the youngster the notion that everything which is important has to be dull." Education has been my business for more than fifty years, and I think I know enough about it to plead guilty to Mr. Edison's indictment. This is too bad, but not so bad it can't be remedied.

In protest against this procrustean bed various "progressive" educational movements have run their riotous courses, sacrificing all serious mental discipline to the untrammeled license of free expression of the child's whimsies. Somewhere between these extremes there lies a sound (but expensive) educational policy. The only reliable way to find out what this policy should be is to learn by carefully controlled experiment just what are the actual results of these various methods of adolescent education in fitting the pupils to meet the exigencies of life. Such investigations are in process, notably the "Eight Year Study" sponsored by the Progressive Education Association, whose report in five volumes appears in 1941.[8] Many similar studies are now going forward and a factual basis is thus laid for urgent educational reforms.

The effective application of these empirical data in actual practice requires an understanding of the adolescent mind, whose achievement is an even more difficult enterprise. Here statistical methods fail us, for we are dealing, not with universals but with particulars. Education is a social program acting with and upon environment. Its machinery is external to the child. But learning is an individual matter with every pupil; nobody else can do it for him. The best that education can offer is stimulus and sympathetic guidance. No returns from our investments in improving educational environment can be hoped for beyond what capacity is inherent in the native endowments of the individual children. No two of these are alike and the most unpromising pupil may surprise us with remarkable achievement when the right approach to his latent capacity is discovered, and above all if the development of these capacities is not inhibited by stupid blundering. These latent capacities are sometimes hard to find; in other instances they express themselves unmistakably. An instructive incident in my own teaching experience may be recalled here.

At about the turn of the century a

[8] Dorothy Dunbar Bromley, *Harpers Magazine*, No. 1090, pp. 407–416, March, 1941.

boy was growing up in an Ohio parsonage. He was a problem child, bright enough, with winning personality and excellent character, but failing in school. The greater part of a high-school course had been mastered, but he loathed it all. Passionately fond of out-of-doors, he would escape from the classroom at every opportunity and roam the fields—not idly but with eyes open and hands busy. He filled the house with stuffed birds, eggs, insects and all sorts of similar vermin. His mother, wiser than most, did not complain of the litter. But the parents were worried. It looked as if he never would finish high school, but was drifting toward the incompetence of a ne'er-do-well.

At this juncture a visiting clergyman sized up the situation, spent a few hours with the boy and his specimens and then said to him:

"Irving, do you know that at college they allow boys to study birds and outdoor things and give credit for it the same as for book-work?"

"What! Do you mean that they would let me mount birds and bugs and show me how to learn their real names and give credit for it—the things I play hooky for now?"

"Yes, something like that."

"Then I am going to college."

"Good idea. But you know you will have to finish high school before they will let you in."

"That finishes me, I suppose. No! I'll do it."

And he did.

I knew nothing of all this when about a year later Irving registered in my freshman class in zoology. He impressed me as a shy, rather backward boy, and I feared he could not make the grade; but later when he began to bring in his life-like mounted birds and other collections I slowly realized that here was that *rara avis*, a born naturalist. He had little interest or aptitude for the refinements of cytology, which were then in vogue in university circles; in language and mathematics he was a dud; but despite these handicaps he did become a great teacher in an eastern university, and the president of that institution asked me if I had another student of Irving's caliber to recommend to him. In our schools and colleges of to-day there is more urgent need of good teachers than of second-rate investigators.

The history of the Young Naturalists' Society is a record of an experiment performed for us unwittingly by a few sixteen-year-old boys who without encouragement or guidance beyond their own circle systematically organized their interests into an educational program which was internally motivated. The formal rules of procedure were conventional, but the design and actual operation of the educational machinery were their own. We have here an example of the way in which a small group of exceptional children educated themselves. They were not emancipated from discipline, but they learned to discipline themselves, each in his own way, and this is the ideal for which we strive in all education.

The records of this society reveal the germinative stages of three successful careers of research at the most critical formative period in their lives. The publication of a digest of these papers is contemplated, including copious extracts exactly as written in boyish emulation of the formal proceedings of great learned societies, spiced with juvenile enthusiasm and the crudities of schoolboy diction.

HOW LIFE BECOMES COMPLEX

By Dr. S. J. HOLMES

PROFESSOR OF ZOOLOGY, UNIVERSITY OF CALIFORNIA

LEST the reader be led to expect a discussion of the distractions of living in our modern society, I may explain at the outset that this is a purely biological article. It deals with the complexities of the life processes in plants and, especially, in animals, and how these complexities came about.

Life presents an enormous range in complexity from that of the human body down to the bacteria or organisms even simpler, such as the filterable viruses, if they are organisms at all. An amoeba carries on the same fundamental life processes as a man, with almost no organs. It moves without muscles, transmits stimuli without nerves, digests without stomach or intestine, respires without lungs or gills, and reproduces its kind by pinching itself in two. An amoeba, which is by no means the simplest form of life, is the product of a long series of evolutionary changes. It occupies a niche in nature in which it has persisted with little change for millions of years, during which other animals have forged ahead and acquired structural organizations of great complexity and almost endless variety. If we compare the structure of a frog, an insect, a clam, a starfish or an earthworm, we find remarkable differences of form and internal organization, but the diverse organs of these animals are devoted to the discharge of the same essential functions. All of them have organs of digestion, absorption, respiration, excretion and reproduction. The varied structures of these animals represent so many different ways of solving essentially the same physiological problems. Why all this bewildering variety of structure and pattern?

Obviously, life as it has become more complex has followed many different paths. For the most part we can not say that one animal solves its problems better than another. The amoeba gets along very well in its way, and so does the starfish, the spider, the squid, the porpoise and all the rest of our animal relatives. They persist and perpetuate their kind, and possibly enjoy life after their fashion, and this is about all a living creature can reasonably expect. As Aristotle observed, the activities of all organisms center about two ends—the preservation of the individual and the perpetuation of its kind. These are the two great problems that face every living creature. Death to the individual or its kind is the penalty for failure to discover the correct solution. Organisms have tried different ways—millions of different ways—of finding an answer to these Sphinx riddles, and the number of right answers that have been hit upon is indicated by the multitudinous diverse types of plant and animal life. A higher type of organization would be of no advantage to a creature in certain situations. If an animal or plant occupies a niche to which it is well adapted, it may persist almost unchanged for an indefinite period of time. The lamp shell Lingula has changed very slightly since the Cambrian period. For animals that bury themselves in the sea beach, life some hundreds of millions of years ago was probably much the same as it is to-day. All along the course of organic evolution there are forms that have found their niche and have stayed there, while others that were more adventurous explored new fields and acquired profound

changes in adaptation to different kinds of environment.

There are some types of environment that favor an advance of organization, and life, which is ever ready to take advantage of opportunities for its own increase, has developed there into higher forms. Nature apparently strives to fill all kinds of situations with living inhabitants. What she seems to be interested in is having as many children as possible. Whether they are high or low in the scale is a quite secondary matter. Certainly, Nature has been remarkably successful in producing offspring of the most complicated structure along many different lines, and we may now consider some of the ways in which she has achieved this end.

One important influence is an indirect result of mere increase in size. Every student of elementary geometry has learned that as a body increases in size its surface increases as the square of its diameter, while its volume increases as the cube. When a body grows, therefore, its volume increases disproportionately to its surface. This fact has very important consequences for living organisms. In a spherical organism of 1, 2, 3 or 4 inches in diameter, for instance, the surface areas would be as 1, 4, 9 and 16, while the volumes would be as 1, 8, 27 and 64. But if the life processes went on at the same rate in these organisms, there would be a more rapid exchange through a given area of surface in the large organisms than in the small ones. As size increases, absorption of nutriment, the elimination of waste and exchange of gases in respiration will have to be carried on so much faster through a given area of surface that further growth would be automatically checked. Perfectly spherical organisms of homogeneous structure, therefore, could not attain a very large size; they never do. Where any considerable size is reached in a plant or animal, it is always attended with structural devices for increasing surface in relation to volume.

A good deal of the complicated anatomy of higher animals is a result of extending surfaces devoted to the fundamental vital processes of absorption, excretion, digestion and respiration. Small animals can obtain sufficient free oxygen by absorbing it through the body wall. But where size increases, relatively more surface is required for respiratory exchange. Aquatic animals quite generally meet the situation by pushing out the integument to form gills. Among terrestrial animals gills, unless protected by structures by which they are kept moist, are usually replaced by organs that ramify within the body and thus keep respiratory surfaces protected from desiccation. Our lungs, for instance, are outgrowths of the anterior part of our digestive tube. The finer subdivisions of the bronchial tubes lead to very thin-walled air cells through which respiratory exchange readily occurs between the air and the blood in the capillaries with which the air cells are richly supplied. If our lungs were ironed out, so to speak, the total area of their surface in intimate association with the blood would be about equal to the wall space of a fair-sized room.

In organs devoted to absorbing food the same principle is abundantly illustrated. Consider the surface of a large tree with its numerous leaves having an expanse which may be more than an acre in area. In this expanse of leaves the carbon dioxide of the air is absorbed and, together with water, is built up into carbohydrates under the influence of sunlight. And in the root system with its millions of root hairs there is a great expanse of surface through which water and salts are absorbed from the soil. Organs of excretion, such as our kidneys with their numerous coiled tubules, are devices for bringing a large area of excretory cells into close relationship with

the blood. The same statement applies to glands of all sorts, whether devoted to the elaboration of digestive juices or the production of other substances. If we survey our own bodily structure or that of any other complex animal and consider how much of its make-up consists of extensions of surfaces involved in absorption, secretion, excretion and respiration, we will find that we have included no small part of its structural complexity.

But the story by no means ends here. In order to live at all every organism, even the simplest, must perform the basic functions of absorption, assimilation, respiration, excretion, conductivity and reproduction. But in order that these basic functions can be discharged in a more highly developed organism, other activities subservient to them have been superadded. Let me illustrate. All organisms must take in nutriment from the outside. In animals the food usually requires to be digested before it can be absorbed and gain access to the living protoplasm. The essential feature of digestion is splitting up food substances by means of enzymes, or ferments until they are rendered capable of solution and diffusion through living membranes. Digestion is a process subsidiary to absorption. The amoeba performs this function in little vacuoles in its protoplasm formed by the secretion of fluid around engulfed particles of food. These vacuoles disappear after their work is accomplished, and the undigested residue of the food is expelled to the outside. They are little stomachs improvised for the occasion. In a hydra we have permanent specialized organs set apart for the function of digestion, but the structures involved are of a very simple and primitive kind. In striking contrast with this is our own digestive machinery with its complicated stomach and intestine and the highly developed glands of liver and pancreas, to say nothing of numerous small glands elaborating their specific kinds of digestive ferments. But where so much apparatus is devoted to digestion and absorption, still more apparatus is required in order that the parts can carry on their work. We have muscle fibers in the walls of the alimentary canal which in the oesophagus aid in swallowing, and in the stomach bring about the churning motions that facilitate the chemical part of the digestive process, while in the intestine they effect the discharge of food along its course. All these parts are equipped with blood vessels which supply oxygen, remove waste and carry away absorbed food materials to be distributed to other parts of the body. And, again, the movements of the muscular coats of the alimentary canal, the secretions of glands and the regulation of the blood supply are coordinated through the agency of the nervous system and also by special kinds of hormones or internal secretions. These agencies are required to make it possible for the parts more immediately concerned in digestion and absorption to function in an adequate manner.

But in addition to the organs that are directly accessory to the digestive apparatus, animals are equipped with tentacles, teeth and various other organs for the capture of prey. The sharp claws of the cat, the poison glands of the spider and the tentacles of the octopus are all devices to enable their possessor to capture prey upon which the digestive juices of these animals may act. But further complications arise by the development of organs and instincts subsidiary to these activities of capturing and overcoming prey. A striking instance is furnished by the common orb-weaving spiders. Toward evening in summer time one may often witness the marvelous performance of spinning an orb web. The making of the frame of the orb, the placing of the rays, the spinning of the spiral of sticky web and the formation

of the central disc, or hub, are carried out with a nicety and precision that have excited the admiration of all observers. The web finished, the spider takes up its position head downward in the center, with its feet on the rays where they readily feel the agitation conveyed by the struggles of an entangled insect. Following the signal, the spider rushes out upon its prey, often employing more web in the endeavor to impede the movements of its victim. Then comes the sudden rush, the burial of the fangs and afterward the leisurely meal. Here we have a complex series of acts in preparation for capturing prey, which in turn is a preparation to the acts of overcoming and feeding upon it, and these activities in turn are more directly subservient to the various acts involved in digesting and absorbing food.

We might take another illustration from the industry of the hive bees, among which there is not only food collecting, but food storing and, in preparation for food storing, the construction of the beautifully regular six-sided cells of the honeycomb. Or, again, we might cite the grain gathering and storing of the agricultural ants and the peculiar fungus-growing industry of certain species of ants and termites. These activities, indirectly accessory to nutrition, often involve the evolution of highly specialized organs for their performance. Among such are the pollen basket on the hind legs of the hive bee, the pollen combs, the wax glands on the underside of the abdomen, and the peculiar wax pincers by which the scales of wax are removed. The whole structure and instinctive behavior of the worker bee have been profoundly modified in relation to the accessory nutritive activities upon which she unselfishly spends so much of her energies. We thus see how, in relation to the primitive function of nutrition, one complication leads on to another, and this again to a third, and so on. The basic vital process of (A) absorption becomes associated with the preliminary and preparatory activities of (B) digestion. These may finally involve elaborate mechanisms for their discharge, but subsidiary to these there are worked in (C) specialized modifications of the muscular and nervous systems, to say nothing of other parts. Subsidiary to the preceding functions we have (D) activities of collecting food, involving, often, complicated structures and modes of behavior, and subsidiary to these, again, we have (E) such acts as web spinning and comb making, and many others, each entailing more or less extensive changes of structure and behavior. In this way life becomes more and more complex.

We see much the same sort of thing exemplified in the development of industry. One may manufacture such articles as cigarettes with a very simple layout. A few girls with very simple apparatus could turn out a goodly number of these articles in a day. But if a primitive plant should grow into a large factory, we would find the installation of more complex machinery and no end of accessory activities. There would be janitors, bookkeepers, stenographers, business managers, traveling salesmen, special buyers, pay clerks, advertisers, night watchmen, and perhaps attorneys and plain clothes detectives, all of whom would be engaged in work subsidiary, directly or indirectly, to the fundamental function of the factory. Although the basic function of nutrition may be a more complicated process than making cigarettes, it comes to require in special cases a vast deal of machinery to carry out the subordinate activities and the activities subsidiary to these, and so on to the spinning of the spider's web and the building of the comb of the hive bee.

It would be instructive to consider another illustration of how complications pile up in the evolution of life, and this

time I will select the process of reproduction, which is certainly a basic vital function characteristic of all species of living organisms. Its simplest manifestation is in the fission of a very primitive form of life, such as a bacterium. The propagation of all but the simplest of the one-celled organisms commonly involves in some part of the life cycle the intervention of sex. So far as is known, the bacteria, the blue-green algae and some other groups are primarily sexless. Doubtless, life existed on the globe for many millions of years before sex entered upon the scene, but it is a significant fact that it never evolved very far. One might indulge in flights of fancy as to what plants and animals might be like if evolution had continued to go on without the development of sex. Certainly, the higher animals, if there were any, would be very different from what they now are structurally, physiologically, emotionally and intellectually. The reader may try to imagine what sort of creatures they would be. His guess would be as good as that of the professional biologist.

We shall not discuss the problem of the biological significance of sex further than to state that its great importance in evolution is attested by the fact that only very primitive organisms were evolved until the advent of sexual reproduction. Then evolution took a spurt upward. The most primitive manifestation of sexual reproduction is the conjugation of two similar simple organisms. Both the nuclei and the surrounding protoplasm of the conjugants fuse to become one flesh, after which, often following a resting stage, multiplication by fission goes on as before. At first there is no clear distinction of male and female, but in many one-celled organisms, plants as well as animals, the conjugating individuals are differentiated into a large, relatively immobile female cell and a much smaller, actively swimming male cell. This differentiation parallels the differences between the ovum, or egg cell, and the spermatozoon of the higher animals.

In all the multicellular animals the sex cells are sharply differentiated into eggs and sperm, but in more primitive groups, such as sponges, corals, jelly fish and many worms and molluscs, sexual reproduction is usually accomplished quite simply by discharging the eggs and sperm into the water and leaving their union to chance. In all but the simplest of the multi-cellular animals the sex cells are produced in specialized organs, often provided with ducts for their transfer to the outside. But sexual reproduction does not involve elaborate behavior or many accessory structures until the development of internal fertilization. This step is one of tremendous importance for further evolution. We see it foreshadowed, as it were, in certain groups of animals in which the fertilization of eggs still occurs outside the body, by the development of instincts that bring about a close association of the sexes during the breeding season. During the period of egg laying in fishes, for instance, the female is closely followed by the male, who frequently rubs against her body and discharges his milt, or sperm, over the eggs as soon as they are extruded. In the breeding season the males of many species develop brighter colors and, sometimes, small bodily protuberances and other structures associated directly or indirectly with the function of mating. These modifications are not, as a rule, extensive. In frogs, toads and some other amphibians a closer association of the sexes is secured by the clasping instinct of the male. As in fishes, the discharge of the eggs from the female prompts the simultaneous discharge of the sperm from her male companion, the eggs being fertilized in the water by the sperm which penetrate their jelly-like covering. That such mating habits probably led to internal fertilization is indi-

cated by the fact that among both fishes and amphibians there are species in which the eggs are fertilized within the body of the female, as they are in all the higher classes of vertebrate animals. But, however fertilization of eggs within the body may have been originally accomplished, the process once started has entailed most elaborate developments; it has led to the evolution of diverse structures for the transfer of sperm cells, organs for clasping the female, and the perfection of organs of sight, smell and hearing which enable the males to discover the whereabouts of the other sex. The enormous eyes of the drone honeybee and the elaborately developed antennae which are the olfactory sense organs of male moths are among the many evidences of the influence of the function of mating upon the evolution of organs of sense. When internal fertilization is once evolved, the male is confronted with the problem of distinguishing the female of his own species from all other kinds of living creatures. Here is one of life's hurdles which must be surmounted if the species continues to exist. Consider, for instance, the nuptial flight of the queen bee. When the young queen makes her first flight into the air, a number of the big-eyed drones immediately start in pursuit. Their course is directed not only by sight but by odor, which they detect by their well-developed antennae, which are much more richly supplied with sense organs than those of the queen or worker. Mating takes place in the air and the process is usually fatal to the male. The sperms are stored in a special receptacle in which they may live for years. Apparently, the queen controls the outlet of this organ because eggs laid in drone cells are not fertilized and hence develop into drones, while those which are fertilized develop into queens or workers. In this case internal fertilization involves not only specialization of the reproductive apparatus of both sexes, but the elaboration of organs in the male useful in distinguishing and following the female. The function of mating has, so to speak, put a premium upon the development of activity, acuity of sense, powers of discrimination and special aptitudes of various kinds. It has thus been a potent factor in the evolution of mind, as well as bodily organization. This is indicated especially by the frequently elaborate behavior of many animals preparatory to the act of fertilization. In birds especially, but also in certain insects and spiders, the male performs various antics while courting the female, as Darwin has described in much detail in his writings on sexual selection. Courtship is obviously an activity subsidiary to the union of the sexes and it has led to the development of many structural features and special instincts for display. The brilliant ornamentation of male birds, so wonderfully manifested in the peacock's tail and the plumage of the birds of paradise, is associated with instincts for the effective exhibition of these attractions. A large part of the courtship of male birds involves also the employment of song. Doubtless, few people have ever reflected that the voice owes its origin and at least the early stages of its evolution to its use as an aid to mating. The power of making sounds is possessed in greater or less degree by many kinds of insects, but where it is conspicuously manifested, as in crickets, katydids and cicadas, it is employed in courtship. In the vertebrates, although there are a few fishes that make noises of uncertain function, the voice proper first appears in amphibians. The breeding season in the spring is the time in which the croaking of male frogs is most vociferous, and it has been observed that the females go to the localities from which the croaking proceeds. In both the birds and the mammals the voice has acquired other than sexual functions, but it still retains

its primitive employment as a sex call, a function which has received perhaps its acme of perfection in the song of the nightingale. To a certain extent vocal sounds are made in connection with the battles of the males for the possession of the females, as is exemplified by the nocturnal encounters of tom cats and the challenge uttered by the bull moose as he goes on the war path against possible rivals. But in these cases also the use of the vocal apparatus is closely associated with the function of mating.

With the evolution of parental care the voice comes to be extended beyond its original sexual function and is employed in different ways in fostering and protecting the domestic group. The danger chirr of the mother quail sends her flock under cover; the cluck of the hen keeps her brood closer around her, and her peculiar call indicative of the discovery of food brings the young chicks to share the prize. And the cry of the young mammal causes the mother to rush to the defense of her offspring or to supply its nutrient wants. Crying, by the way, plays a very important biological function which human beings share with their humbler mammalian relatives. It is the part of human language which rests upon a basis of pure instinct. It is a call for help prompted by hunger, distress, fear or perhaps merely the desire for attention, as it may come to be in spoiled babies. On the other hand, the response of the mother to the cry of her infant is doubtless prompted by a strong instinctive impulse even in human beings, as it clearly is in lower mammals.

As social groups come to be evolved, the voice comes to be employed as a means of integrating the activities of the members. Warning cries, grunts of satisfaction in comradeship, cries of distress that bring others to the defense of an animal that is attacked and many other utterances which are instinctively made and instinctively responded to are wide-spread among the higher social and gregarious animals. Finally, in man the voice comes to be employed in articulate speech with all that this implies for the further evolution and cultural development of mankind.

We have already commented on our inability to predict what kind of organic world would have been evolved had it not been for the advent of sex. Very probably its highest products would have been voiceless, and since organs of hearing tend to go along with organs for the production of sound, the creatures would have probably also been deaf.

I must point out also another line of development which has grown out of activity associated with, and subsidiary to, the function of reproduction. This is the evolution of parental care. Maternal affection does not enter upon the scene until comparatively late in the evolution of animal life. The whole vast groups of worms, molluscs, echinoderms and crustacea do not manifest the least solicitude for the welfare of their offspring. The same statement is true for the great majority of insects, spiders, fishes and amphibians. Among the lower invertebrate animals the discharge of the sex cells into the water fulfills all responsibility for the perpetuation of the species. In the higher invertebrates the simple physiological functions of producing and discharging sex cells are accompanied by accessory activities of various kinds. Many species of insects devote much care to laying eggs in situations that provide food for the future larvae. One might write a whole treatise on the varied and highly specialized modifications of egg laying. The cabbage butterfly is careful to deposit her eggs upon cabbages, mustard or some other member of the natural order of Cruciferae. The mother blowfly chooses meat, if tainted so much the better. The solitary wasp, according to its kind, hunts out a narrowly restricted group of beetles, grasshoppers or insect

larvae, stings her victim so as to paralyze but not to kill it, lays an egg upon it, buries it in a hole, carefully fills the hole with dirt, then leaves her progeny to its fate. No maternal affection here. In fact, the mothers do not recognize their offspring as any kin of theirs, if they see them. Normally, they never do see them. The whole elaborate and highly specialized performance is gone through blindly and instinctively. There are many kinds of insects which spend much effort in making receptacles for eggs and in storing food for their progeny. Numerous species of solitary bees provision their nests with pollen and honey which the larva feeds upon. Only in a few species do the mother bees remain with the nest and supply food directly to the larvae after they have hatched from the eggs. Care for eggs long antedates care for what comes out of the eggs. But when the association between the parents and their living offspring was once established, a line of evolution was started which has led to the most momentous consequences for the further development of animal life.

I shall pass over the manifestations of care for offspring as it has developed in ants, bees and termites among social insects, and its temporary appearance in a few groups of fishes in which the parents may accompany the young for a short time until the school becomes scattered. In birds one may find various stages from types in which the parents foster and protect the young for a short time and then leave them to shift for themselves, to the domestic behavior of the higher song birds which raise their broods in carefully constructed nests and spend much of their time in keeping the nests clean, brooding their offspring and finding food to fill their hungry mouths. The more care is expended on offspring the more helpless they become, and the more dependent they are upon the ministrations of their parents. Successive generations become more closely tied together. In solitary wasps they are completely separated. Neither knows the other. In the robin they are intimately united for a prolonged period. One may often see a nearly full-grown robin soliciting and receiving food from its indulgent parents after it is perfectly able to forage for itself.

Among the mammals, the care of offspring has become part and parcel of the perpetuation of life. In fact, the possession of mammary glands, the unique structural feature to which the class of Mammalia owes its name, would be valueless in the absence of the maternal instinct to foster and nourish the young, and the correlated instinct of the young to obtain its food from the maternal fount. As in birds, parental care increases, as a rule, as we pass from lower to higher forms. In the apes it is exhibited in many ways that appear quite human. We may regard it as the source of social sympathy and affection. It is the earliest form of true altruism. Without it man would probably never have become a "moral animal," as he was said to be by Herbert Spencer.

Parental care, as I have attempted to show (although lack of space forbids producing sufficient evidence for this conclusion), is an outgrowth of accessory reproductive activities which have been superadded to the more primary reproductive functions. If it has afforded the evolutionary basis for altruistic behavior it is because reproduction is fundamentally and essentially an altruistic function. It is concerned not with the individual *per se* but with others. We can not say that altruism evolved out of egoism. Both are present in the simplest organism that divides by fission. Both are coeval with life itself.

In discussing the ways in which life comes to be more complex I have taken for purposes of illustration a few of the

basic functions of living. One might show how complexities heap up in relation to various other fundamental life processes. But evolution along any one of these lines has important interconnections with other lines, and it frequently happens that organs developed for one function become worked in to perform other functions as well. The web spinning of spiders, to which we have alluded, whatever its original use may have been, is employed not merely as accessory to food getting, but for making nests and retreats, for making cocoons for enclosing the eggs, for constructing the neatly-fitting door of the trapdoor spider, for so-called ballooning habits by which young spiders are carried for great distances by the wind and for a number of minor functions in different species of spiders. Thus, a function evolved as accessory to another function, which may itself be accessory to a third, may branch out on its own account and lead to a great variety of developments.

During the long course of its evolution life has always been seeking for aid in trying out all sorts of new ways of doing in the endeavor to find any that may be helpful somehow in carrying on its more fundamental processes. The young girl I saw a few minutes ago who stopped to powder her nose and apply her lipstick with the aid of a small mirror was engaged in activities indirectly accessory to maintaining the stream of life. It is because we have taken on so many of these indirectly subservient activities that we have finally come to be so fearfully and wonderfully made.

NEUTRINOS VS. SUPERNOVAE

By Dr. G. GAMOW

PROFESSOR OF THEORETICAL PHYSICS, GEORGE WASHINGTON UNIVERSITY

Stellar Evolution

What are the sources of energy radiated in such large amounts by different stars and, in particular, by our own sun? How long have these sources been in action, and how long can they still last? What changes, if any, can one expect in a star during its course of evolution? Those are the questions which have presented themselves to the human mind ever since the inception of scientific astronomy and which represent at present probably one of the most interesting and exciting problems of theoretical astrophysics.

All previous attempts to account for stellar radiation as due to some chemical reactions (burning) taking place in the stellar interior, or to consider it as the result of the steady contraction of the stellar body, fell short of their aim since the amount of energy liberated in such processes was not enough by far to explain the long existence-period of the stellar universe.

Only the discovery of radioactivity and the recognition of the vast amounts of subatomic energy stored in the interior of tiny atomic nuclei opened the way for the understanding of stellar energy sources and stellar evolution. It was shown by Atkinson and Houtermans as early as 1929 that the extremely high temperatures (about 20,000,000° C) existing in the stellar interior must induce the processes of nuclear transformations similar to those which we obtain under laboratory conditions by bombarding various elements with very fast particles. Using the quantum theory of nuclear processes, they have been able to show that, under conditions existing in

the stellar interior, the protons, animated by a rapid thermal motion, will easily penetrate into various light nuclei causing their disintegration, and liberating amounts of subatomic energy sufficient to support stellar radiation over a period of many billion years.

But, although it was already clear at that time that the thermonuclear reaction responsible for the energy supply of stars must be taking place between hydrogen nuclei (protons) and the nuclei of some other light element, the insufficient knowledge of various nuclear processes prevented the discovery of the reaction itself. And it was only recently (1939) that the particular nuclear reaction, or rather chain of reactions, responsible for the energy production in the sun and all other stars of the main sequence was found by Bethe. According to Bethe, the light element which reacts with hydrogen (in the nuclear sense) at the high temperatures of the stellar interior is ordinary carbon. Penetrating into the interior of carbon nuclei, protons emit their surplus energy in the form of hard γ-rays, and remain in the bound state, thus giving rise to somewhat heavier nuclei. However, the nucleus of carbon can not hold more than four protons and, as soon as the saturation point is reached, it "spits them out" in the form of a single α-particle, or the nucleus of a helium atom. The carbon nucleus emerging from this process in its original form is ready again to capture new protons and to unite them into a new α-particle. Thus we see that the carbon plays only the role of what the chemists would call a catalizer, and the net result of nuclear reaction is the transformation of hydrogen into helium.

Estimating the total energy which must be liberated in this carbon-cycle at the temperatures existing in the interior of the sun, Sirius and other stars, Bethe was able to show that it coincided with the observed radiation of these stars.

Since the nuclear reactions, transforming hydrogen into helium, cause definite changes in the physical properties of stellar matter, one should expect that they must result in certain changes of the observed characteristics of the star itself. This question was studied in some detail by the author of this article, and it was found that the steady decrease of the hydrogen content in the star must lead to a quite considerable increase of its luminosity. The radius of the star suffers but very little variation, so that the increasing luminosity must be connected with a progressive increase of the surface temperature. Thus, for example, in the case of our sun, the decrease of the hydrogen content from its present value of 35 per cent. down to 1 per cent. (this decrease requires about 10 billion years) will increase the luminosity by a factor of a hundred, and make the surface of the sun so hot that the astronomers of the future will classify it as a class A star. It is needless to say that these will be, in any case, not terrestrial astronomers since, due to the increase of solar light and heat, the surface of our planet will be by that time very hot indeed (about 300° C) and life on it will be quite impossible.

After the star, following the path of its evolution, reaches this state of maximum luminosity, the hydrogen content in its body will be entirely exhausted. In the absence of hydrogen, the energy liberation due to nuclear transformations drops down to zero, and, being deprived of its subatomic energy sources, the star is bound to start a slow contraction. During these late stages of stellar evolution, the radiation of the star is supported by the gravitational energy liberated in contraction, and the luminosity of the aging star is gradually dropping down. The final stage of the contraction must be represented by a very dense star which might be, however, still quite hot. Examples of such dying stars are given by the so-called "white dwarfs" possessing very low luminosities, and the esti-

mated density exceeding the density of water by a factor of several hundred thousand. Afterward such a "white dwarf" star will finally cool down, its luminosity will drop down to zero, and we will have a dark stellar body of extremely high density. Such "black dwarfs" are probably rather numerous in the inter-stellar space, but escape astronomical observation because of the lack of sufficient radiation.

Stellar Catastrophes

The process of stellar evolution, described in the previous section, is a slow, continuous process and all changes in the luminosity and geometrical dimensions of the star require many millions of years. Astronomical observations tell us, however, that very often stars undergo changes of a much more catastrophic character, the process being known as a nova explosion. Within a few days, a star, which did not seem before to differ much from any other star in the sky, increases its luminosity by a factor of several hundred thousand and its surface becomes evidently extremely hot. The study of the changes in the spectrum accompanying this sudden increase of luminosity indicates that the body of the star is rapidly swelling up, and that its outer layers are expanding with the velocity of about 2,000 kilometers per second. The increase of luminosity is, however, only temporary, and, after passing through the maximum, the star begins slowly to settle down. It takes usually about a year before the luminosity of the exploded star returns to its original value, though small variations of stellar radiation have been observed after considerably longer time intervals. Although the luminosity of the star becomes normal again, one can not say the same about its other properties. A part of the stellar atmosphere, participating in the rapid expansion during the explosion phase, continues its outward motion, and the star is surrounded by a luminous gas shell of gradually increasing diameter. The evidence concerning permanent changes of the star proper is as yet very indecisive, as there is only one case in which the spectrum of the star was photographed before the explosion (Nova Aurigae 1918). But even this photograph is seemingly so imperfect that the conclusion concerning surface temperature and the radius of the pre-nova stage must be considered as very uncertain. However, it seems that the collapse process may be connected with the increase of surface temperature, which, in view of about equal luminosities of pre- and post-novae, would indicate a smaller radius.

Somewhat better evidence concerning the result of the explosion in the body of the star can be obtained from the observations of the so-called supernovae explosions. These vast stellar explosions, which happen in our stellar system only once in several centuries (in contrast to ordinary novae, which appear at the rate of about 40 per year) exceed the luminosity of ordinary novae by a factor of several thousand. During the maximum, the light emitted by such an exploding star is comparable with the light emission of the entire stellar system. The star observed by Tycho-Brahe in 1572 and visible in bright daylight, the star registered by Chinese astronomers in the year 1054, and probably the Star of Bethlehem represent typical examples of such supernovae within our stellar system, the Milky Way.

The first extragalactic supernova was observed in 1885 in the neighboring stellar system known as The Great Andromeda Nebula, its luminosity exceeding by a factor of one thousand the luminosities of all other novae ever seen in this system. In spite of the comparative rarity of these vast explosions, the study of their properties has made considerable progress in recent years due to observations of Baade and Zwicky, who were the first to recognize the great difference

between the two types of explosions and began the systematic study of supernovae appearing in various distant stellar systems.

In spite of the tremendous difference in luminosity, the phenomena of supernovae explosions show many similar features with the ordinary novae. The rapid rise of luminosity and its subsequent slow decrease in both cases are represented (apart from the scale) by practically identical curves. As in the case of ordinary novae, a supernova explosion gives rise to a rapidly expanding gas shell, which, however, takes a considerably larger fraction of the stellar mass. In fact, whereas the gas shells emitted by novae become thinner and thinner and dissolve themselves rapidly in the surrounding space, the gas masses emitted by supernovae form extensive luminous nebulae involving the place of explosion. It can be, for example, considered as definitely established that the so-called "Crab Nebula," seen at the place of the supernova of the year 1054, was formed by gases expelled during that explosion.

In the case of this particular supernova we also have some evidence concerning the star remaining after the explosion. In fact, in the very center of the Crab Nebula, observations show the presence of a faint star which, according to its observed properties, must be classified as a very dense white dwarf.

All this indicates that the physical processes of supernovae explosion must be very analogous to those of the ordinary novae, although everything is happening on a much larger scale.

The Cause of Stellar Collapse

Assuming the "collapse-theory" of novae and supernovae, we must first of all ask ourselves about the causes which could lead to such a rapid contraction of the entire stellar body. It is well established at present that the stars represent giant masses of hot gas, and that in the state of equilibrium the body of the star is supported entirely by the high gas pressure of the hot material in its interior. As long as the various thermonuclear processes, described in the first section of this article, are going on in the center of the star, the energy radiated from the surface is being replenished by subatomic energy produced in the interior, and the state of the star changes but very little. As soon, however, as the hydrogen content is completely exhausted, no more subatomic energy is available and the star must begin to contract, thus turning into radiation its potential energy of gravity. The process of such gravitational contraction will, however, go very slowly, since, because of the high opacity of stellar material, the heat transport from the interior to the surface is very slow. It can be estimated, for example, that in order to contract to half of its present radius, our sun would require more than ten million years. Any attempt to contract faster than that would immediately result in the liberation of additional gravitational energy which would increase the temperature and gas pressure in the interior and slow down the contraction. It can be seen from the above considerations that the only way to accelerate the contraction of a star and to turn it into a rapid collapse as observed in the case of novae and supernovae, would be to devise some mechanism which would remove from the interior the energy liberated in contraction. If, for example, the opacity of stellar matter could be reduced by a factor of several billions, the contraction would be accelerated in the same proportion, and a contracting star would collapse within a few days. This possibility is, however, quite excluded, since the present theory of radiation definitely shows that the opacity of stellar matter is quite definitely a function of its density and temperature, and can hardly be reduced even by so much as a factor of ten or hundred. McCrea's hypothesis, according to which the excess energy is

escaping from the stellar interior in the form of cosmic rays, also fails in this case. In fact, although the penetrating power of cosmic rays is considerably higher than that of ordinary radiation, they still will be completely absorbed before they pass even a negligible fraction of the stellar radius.

It was recently proposed by the author of this article and his colleague, Dr. Schenberg, that the real cause of stellar collapses is due to certain tiny particles, which were but recently introduced in physics and are known under the name of neutrinos. The necessity for the introduction of this new kind of particles, which are entirely different from any other particles yet known to physics, resulted from the detailed study of the so-called β-decay of radioactive bodies in which the unstable nuclei of various elements disintegrate with the emission of free electrons (β-particles). A very peculiar property of the process of β-decay consists in the fact that, whereas different nuclei of the same radioactive element emit electrons with widely varying energy, there is no trace of any other radiation which would compensate for these differences. Very careful calorimetric measurements carried out by Ellis (in 1927) and repeated still more carefully by Meitner (in 1930) definitely established that there is a discrepancy in the energy balance of such transformations, and yet, using very thick lead-absorbers, one was unable to "catch" anything else than original electrons.

To this unexplainable loss of energy was added an analogous trouble with the angular momentum of decaying nuclei, and one was facing the possibility of either discarding the conservation laws of energy and momentum, or introducing some new kind of hypothetical particles which would carry them away in an "unobservable way."

It was first suggested by Pauli that these run-away particles, which he called "neutrinos," can account for all observed discrepancies if one supposes that they carry no electric charge and possess a mass considerably smaller than the mass of the electron. During the last ten years, neutrinos gained a considerably important position in nuclear physics, in spite of the fact that all the attempts at their direct observation have inevitably failed. The difficulty of detecting these new particles through some direct effect can be, however, simply understood on the basis of theory, since it can be calculated that the neutral particles of such small mass would easily pass through many thousands of kilometers of lead without suffering any absorption! The character of neutrinos has been very ingeniously summarized by Dr. Swann, who said, "The neutrinos are like the world war debts. You never expect to see it paid, but you satisfy your conscience and the conscience of your debtor by keeping it on the records."

It is clear from the above description of the new particle that it is just the right agent to remove the surplus energy from the interior of a contracting star, since the entire body of the star is just as transparent for neutrinos as a window pane is for ordinary light. It remains to be seen whether the neutrinos will be produced, and produced in sufficiently large numbers in the hot interior of a contracting star, and the investigataions of the author of this article and Dr. Schenberg show that this is just the case.

The reactions which must be necessarily accompanied by emission of neutrinos consist in the capture of fast-moving electrons by the nuclei of various elements. When a fast electron penetrates inside of the atomic nucleus, a high energy neutrino is immediately emitted, and the electron is retained, transforming the original nucleus into an unstable nucleus of the same atomic weight. Being unstable, this newly formed nucleus can exist only a definite period of time, and subsequently decays,

emitting its electron in the company of another neutrino. Then the process begins again from the beginning, and leads to a new neutrino emission. . . .

If the temperature and density are high enough, as they are in the interior of contracting stars, the energy losses through neutrino emission will be tremendously high. Thus, for example, the capture and reemission of electrons by the nuclei of irom atoms will transform into neutrino energy as much as 10^{11} ergs per gram per second. In the case of oxygen (where the unstable product is radioactive nitrogen with the decay period of 9 seconds) the star can lose even as much as 10^{17} ergs per second per each gram of its material. The energy losses in this latter case are so high that the complete collapse of the star takes place in only twenty-five minutes.

Thus we see that the beginning of the neutrino radiation from the hot central regions of contracting stars gives us the complete explanation of the causes of stellar collapses, and, since the neutrinos escape all available methods of observation, the origin of the energy discrepancy discussed in the previous section becomes also quite clear.

It must be stated, however, that although the rate of energy losses through neutrino emission can be estimated comparatively easily, the study of the collapse process itself presents considerable mathematical difficulties. It can be said at present only that the beginning of the neutrino emission from the interior of the star will lead to the formation of a dense central core which will rapidly increase in density at the expense of the additional material squeezed into it by the collapsing exterior layer.

For the stars of comparatively small mass (smaller than Chandrasekhar's critical mass of 1.40 sun masses) the process will be stopped as soon as the density of this core reaches a certain maximum value. In this case the result of the collapse will be represented by a dense white dwarf with a mass only somewhat smaller than the mass of the original star.

If the mass of the star is above this critical value, there is no theoretical lower limit for the possible collapse, and the process will go on with ever-increasing intensity until the material blown away in the form of the expanding gas shell reduces the mass enough to stop the process. In this case the result of explosion will be also a white dwarf, but its mass will be much smaller than the mass of the original star. The rest of the mass will be distributed in the form of a gas nebula around the place of explosion.

Comparing these two possibilities with the description of novae and supernovae given in the previous section, we see that it is very probable that the differences between these two classes of stellar explosions may be due to the difference in mass.

We conclude by indicating the connection of the above theory of stellar explosions with the continuous stellar evolution as described in the beginning of this article. Since the emission of neutrinos leading to the catastrophic collapses of the stars takes place only at very high temperatures, we must expect that it will take place during the contractive part of stellar evolution following the complete consumption of hydrogen. Once the collapse starts, it will not stop until it transforms the star into a white dwarf, and thus covers in a few weeks the entire evolutionary path which would otherwise require many million years.

If the proposed theory is correct, we should not worry that our sun may explode any day, since its hydrogen content is still about 35 per cent. On the other hand, the collapse of the sun, taking the form of an ordinary nova, must necessarily be expected about ten or twenty billion years from now.

THE PHYSICAL AND THE NON-PHYSICAL WORLDS AND THEIR INTERMEDIATE ELEMENTS

By Dr. GUSTAF STRÖMBERG

MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

In scientific research it often happens that, when a particular field of study has been explored, an impasse is reached. The principal reason is that the limitations of the field have become apparent, although many details still need to be investigated. In general, the fields and their limits are determined by the categories we use in describing the phenomena belonging to the different fields of knowledge. Our knowledge and our thinking are based on our inherited mental equipment, and our ideas and concepts have developed from our primary sense data, analyzed and synthesized by our intellect. Our sense organs give us such data as apparent extensions, separations and changes of visual images, perceptions of colors, sounds, taste, smell, pain, heat, cold, and touch. We also have feelings of happiness and sorrow, we have a conscious will, we have a memory, and we are able to make deductions and find rules for the activities in our mind and, to some extent, in other minds. If we regard science as any kind of systematized knowledge, we may say that each of our sense organs, using this term with a very broad meaning, defines a particular field of scientific research. These fields are all *mental,* because we always start from sense data and phenomena of one kind or another, and, whatever mental operations we perform, the result is still a mental world. With the aid of intellectual intercourse we can in many cases combine the individual, private mental worlds into a *communal* or *intersubjective* mental world, which we naturally regard as being more fundamental than the private world of phenomena in each individual mind. This is the procedure scientists have adopted in studying what they call the "external world."

Our fields of knowledge fall into two distinct groups. The first is usually based on our sense of vision and is called the *physical world.* The other group contains all those fields the knowledge of which has been primarily derived with the aid of other sense organs, or which are the results of intellectual analysis of a complex nature, and these fields define what we shall call the *non-physical world.* Phenomena belonging to the second group are often called "mental," but this is not a distinctive term, since the physical world, both the private and the communal, must be pictured in categories conditioned by the human mind. There are also elements which lie between the physical and the non-physical world, and we are at liberty to assign them to either one or both of these worlds. These *intermediate elements* are very important, because by studying them we can learn how to pass from one field to another, and we shall then realize the unity behind all our knowledge.

I. The Physical World

We shall define the physical world as a field of intersubjective knowledge in the description of which we need only the categories *space* and *time,* and we use them in the form of spatial and spatio-temporal *structures.* The sense

organ involved is usually that of vision, but the eyes themselves play only a secondary role in our space and time perceptions. We can observe space and time phenomena in a dream, for instance, in which case our eyes certainly play a very subordinate role. There are reasons to believe that the organ of space and time perception is located in the rear part of our brain, which organ not only seems to give us immediate perception of *extension* and *separation* of images (mental space), and immediate perception of *duration* and *progress* (mental time), but also makes possible a coordination of our space and time perceptions into a coherent unit. This organ serves as a "mental clock" and gives us the unique direction of the "arrow of time" and makes possible our perception of events as being "now-here" and "then-there."

The idea that our organ of vision (eyes and brain) can give us complete knowledge of the physical world has recently been emphasized by Eddington.[1] He writes: "Ideally all our knowledge of the physical universe could have been reached by visual sensation alone—in fact, by the simplest form of visual sensation, colorless and non-stereoscopic." In more detailed studies, however, we use many kinds of instruments to aid our vision and to measure, directly or indirectly, distances, displacements, time intervals, and motions. Such instruments are microscopes, telescopes, measuring rods, micrometers, theodolites, thermometers, balances, clocks, galvanometers, photographic cameras, spectroscopes, and so on. An important mission of the eyes is to convert the physical phenomenon, radiation, into the non-physical phenomena, sensations of light and color. Tactile sensation can also be used in the study of physical phenomena, although the tactile sensations themselves, like colors and sounds, belong to the non-physical world.

Kant realized clearly that in our mind we have an inherent, latent knowledge of space and time. The science of physics is not concerned with the metaphysical problem of the existence and nature of space and time. Physicists are particularly interested in *structures* in space and time, which Eddington[2] clearly expresses in the following words: "Since the external world is introduced as a receptacle of structures, our knowledge of it is limited to structural knowledge; and physical science is the study of this structural knowledge." This can be most easily seen when we describe an electromagnetic field. The mathematical description is given by Maxwell's equations, which can be visualized as representing a system of lines of force. Obviously the description is that of a structure with space and time properties, or, better expressed, a *structure in space-time.* The last type of description was introduced by Einstein and is based on the measurements of many individuals having different positions and motions, and refers hence explicitly to the communal or intersubjective world. The structure of an electromagnetic field is characterized by certain well-defined "singularities" or "sources," where the lines of force seem to begin or end.

The *particles* of physics can be described in two different ways. On the one hand they are *sources* in gravitational or electrical fields, and, being important characteristics of the field, that is, of a space-time structure, can be regarded as belonging to the physical world. On the other hand, the particles have rest-masses, angular momenta, and in some cases at least, electric charges,

[1] "The Philosophy of Physical Science," p. 197. Macmillan, 1939.

[2] *Op. cit.*, p. 209. Eddington uses the term "structure" in the sense in which it is defined and investigated in the mathematical theory of groups and does not explicitly limit himself to structures in space and time. *Cf.* p. 147 of Eddington's book.

of definite amounts, or integral multiples of such amounts, a fact which indicates that they have properties which can not be expressed in terms of our concept of space and time alone. The particles themselves therefore transcend the physical world as previously defined. They seem to have their "roots" in a non-physical world, and *they emerge into the space-time world as sources in a field of force.* They belong to the class of intermediate elements mentioned before.

When we speak about the location and motions of particles, or of matter in general, we are referring to measurements and sensations of certain types. We never observe the particles themselves, but *infer* their position and motions by indirect methods, as, for instance, by their effect on light beams or from tactile sensations. The phenomena we observe are associated with their fields and not with the particles as such. It is customary to assume that the elementary particles, like electrons and neutrons, have no internal structure. In making this assumption we have relinquished all rights to regard them as physical objects and have actually placed them beyond the physical world. In a perfectly uniform medium, location, separation, distance, and motion can not be defined and are therefore meaningless concepts. Similarly, time-intervals are non-definable when nothing observable happens. A space without definable structure, and a time during which nothing observable happens seem to be meaningless concepts. We may therefore regard structureless and inactive particles as "openings" in the field or structure. To these openings we can not apply our ordinary concepts of space and time. A similar idea has been expressed by Weyl[3] in his important article, "Was ist Materie?"

Let us assume, for instance, that we have a homogeneous electron beam passing through two slits, close together. We expect then to find the well-known diffraction effects, and the diffraction pattern can be interpreted as a probability distribution of momenta and positions, and the "cells" in the distribution are defined by the value of the quantum of action. This must also hold for a *single* electron, and the diffraction pattern can then be regarded as a potential probability distribution of momenta and positions of the electron. It is now known that an electron is not a recognizable individual that is now here and now there. According to what we have said before, an electron which does nothing is a meaningless idea. We have therefore no right to speak about an electron moving through one slit rather than the other, since no observable effects are produced at the slits. (If such effects were produced, the interference pattern would be greatly modified.) An epistemologically sound imagery should therefore not involve any moving electron at all, but a motion of a "field structure," a "wave system" or a "wave packet" with potential properties and with dimensions much greater than that of the electron itself. This wave system interacts with the wave systems surrounding all particles of matter and is therefore affected by *both* slits. Somewhere in these wave packets and at some time defined by a probability function we expect the mysterious thing we call an electron, of whose ultimate nature we know nothing, to jump like a "jack-in-the-box" into the physical world and then to become recognizable by definite effects on the field.

It is very significant that the effects of electrons and photons are *discontinuous events,* and that, when something observable happens, a definite amount of action emerges into the physical world, and is later temporarily lost to this world. It is for this reason we speak of

[3] *Die Naturwissenschaften,* 12: p. 611, 1924.

"electron jumps" and "excitation steps." When no such events occur, an electron or a photon is in principle unobservable and can therefore well be regarded as non-existent. It seems that it is only the *probability* of its emergence in the world of space and time that can be represented by mathematical functions. Some of the conservation laws of physics may well have only statistical validity. The *wave functions* in multidimensional configuration space, which are needed to describe phenomena in which many particles are involved, can be regarded as mathematical symbolic expressions which have no counterpart in the physical world. They are derived from space and time measurements and must again be converted into such data when comparison is made with actual measurements. They belong to the mathematical implements needed in the science of physics, but not to the physical world of our immediate experience.

It may seem strange to many that, in our analysis, matter has lost its "substance" and nothing is left but a space-time structure. This profound change in our primitive notions is a consequence of the growing powers of our thinking. We have learned that physics starts with *shadows* and therefore never reaches the substance; it describes *form* and *changes in form*, but not the actual content of our experience. For instance, when we study an x-ray photograph of a crystal, we find shadows which our analysis tells us are produced by exceedingly small elements arranged in well-defined formations. We have not the faintest idea of the intrinsic nature of these elements, because we have never had any actual "contact" or "association" with them. (Such contacts can only be established with certain nerve cells in our own bodies, as will be explained later.) We see the formations as recurrent shadows, and we deduce rhythmic vibrations, and a strange "music" is emitted which we picture as a radiation. We wonder whether the structure and the vibrations are due to something inherent in the individual particles, or in the field, or are arranged by an unseen marshal and bandmaster, or whether they are modes characteristic for our own mind, which itself may determine the rules that apparently govern the activities we perceive. Our vision informs us about structural characteristics only, including numbers of similar units and groups with identical configurations, but the cause of the structural properties and of the uniform elements is not revealed by our sense of vision. Nothing should prevent us, however, from using our intellect to the best of our ability to interpret our observations and to look behind the screen on which the shadows move.

Fields of force, radiation, waves, and particles are *constructs of the human mind.* They are invented by ingenious story tellers to describe and to explain the observed shadow play; in pictorial form for most of us, in mathematical form for people interested in quantitative research and in practical applications, and in more abstruse terms for the philosophically minded. Like all allegories the stories are expressed in terms and symbols appropriate to the understanding of the people to whom they are presented, and they emphasize particular features of our experience and disregard others. The pictures and symbols are very instructive and helpful, and they tell us among other things that, beyond the play of shadows we observe in common with others, there exists another world, less evanescent and more fundamental than that revealed by our observations in the realm of space and time.

All this may at first seem of some metaphysical interest, but of little practical importance. But the distinction between a physical and a non-physical

world, and the idea of elements intermediate between them, can be applied to a number of other fields of knowledge, in particular to those connected with life and with consciousness. We shall then see how these new ideas in physics can help us to understand the organization in the living world and the relationship between mind and matter, problems which have hitherto defied all attempts at solution.

II. The Non-Physical World

The non-physical world, like the physical world of space and time, is a mental world and exists in the first place in the consciousness of each individual. The sense organs and brain centers involved are of the most varied types; in fact, all sensations which are not of extension, separation, structure, structural changes, vibration and motion belong to the non-physical world. Colors, sounds, smell, taste, pain, touch, feelings, emotions, memories, conscious will, thoughts, and purposeful activities belong to this world. Life itself, apart from its purely physical, that is, structural, aspect, belongs to the non-physical world. Life, *as we see it*, is a play of moving shadows in our consciousness and hence belongs to the physical world. The purposeful organization behind this play of shadows, the life we feel in our bodies, and the life associated with conscious activities, on the other hand, belong to the non-physical world.

It is, of course, impossible in a short article to describe all the phenomena and concepts belonging to the non-physical world. Many of them, together with a general survey of the problem, have been described in a non-technical book[4] recently published. I shall here describe only two types of phenomena which are characteristic for the whole field and are of great importance for our understanding of the universe in its wider aspects.

[4] G. Strömberg, "The Soul of the Universe." Philadelphia: David McKay Company, 1940.

A. The Origin of Colors

We all know, or think we know, what radiation is. The physicists agree that it is an electromagnetic phenomenon, and we know a great deal about the physical properties of radiation. Radiation can produce chemical and electrical effects, but it can also produce a sensation of light or color. We have definite ideas about the mechanism involved in the production of the physical effects by radiation, but when we come to an explanation of color sensations, our mind is completely blank. We rarely give any thought to the problem how the transformation of radiation into colors is accomplished; in fact, the general relationship between physical and mental phenomena is a problem which long ago was given up as insoluble and even incomprehensible. A solution of this age-old problem would open up a whole new world for our investigations and might well change our whole outlook on both life and mind. Hence it is of importance to make some serious efforts to elucidate this important problem.

The generally accepted idea is that the radiation produces some chemical changes in the retina, and the unstable chemical substances thus produced stimulate the rods and cones at the ends of the optic nerve fibers. These nerve fibers are associated with one or more ganglia, and the nerve fibers can be regarded as extensions from nerve cells in the ganglia. The nerves with cones at their ends give us color sensations, whereas the rods are responsible for gray or colorless sensations and are sensitive to faint light. To simplify our description we shall in what follows regard "white" as a particular kind of color sensation.

The word "stimulation" is a convenient term, but it does not tell us anything about the origin of the colors. We have no more reason to believe that atoms and molecules can by themselves give us a sensation of color than that they can feel and think. If atoms could have such

strange faculties, it is difficult to understand why they can be effective only when they vibrate in certain ways and form certain peculiar structures, like those in the optic ganglia and in the brain. The structure of the optic ganglia is determined by hereditary elements in the human ovum, and these elements we shall call the *color genes.* In fact, many believe that we can definitely locate the potentiality for red vision in the X-chromosomes, of which a man has one and a woman has two in all living cells of their bodies. It is necessary to assume that the field structure of the color genes in the ovum has expanded or become developed at certain definite places in the retina of our eyes. These fields guide the motions of particles and have a specific structure of a highly complex type. In living elements, like the optic ganglia, the field can not be conditioned by the incorporated material elements alone, *the field must have a structure of its own* and determines in itself the molecular structure and vibrations. Our first conclusions are then that the *fields* in the ganglia, rather than the incorporated material elements, are essential factors in the mechanism we study, and that these fields exist in an extremely contracted or potential form in the fertilized ovum.

All fields of force must have *sources* which define their properties. In an electric field the sources are in the electrons and in the atomic nuclei; in a gravitational field the sources are in the atoms, probably in the neutrons. In analogy with the ideas expressed before, we shall regard the field as the physical or space-time aspect of a phenomenon. The corresponding sources, on the other hand, belong to the non-physical world and represent the *non-physical essence of the activities,* which essence, like that of electrons and other particles, emerges at fairly well-defined loci into the physical world of space and time. It then appears in the form of fields with certain specific physical properties, and the points mentioned we picture as singularities in the field. The properties of the fields are conceived as actual and physical, whereas the properties of the sustaining sources are potential and non-physical.

A field of force has a certain energy content. Part of this is in the field and part is in the sources, and the latter part can be measured by the rest-mass of the sources. The masses of different types of sources differ greatly. Electrons have very small rest-masses, neutrinos probably very much smaller, and photons none at all. "Living sources" have probably no rest-masses at all, and all their energy is then in their fields. When a "living field" disappears from the physical world, energy is lost, and, when it emerges or grows, a certain amount of energy is absorbed and organized. The fields in atoms and molecules can absorb radiant energy. In this case the structure expands or is split, and these phenomena we call excitation and ionization, respectively. In the case of living fields the energy needed for their emergence and expansion can be obtained in several ways. The most common way is by chemical substances having a structure with a frequency pattern similar to that of the field itself. Such substances we shall call *hormones,* because they act in the same manner as the hormones which stimulate growth and embryonic development and enhance the activities of our organs. In nature, hormones are usually formed by resonance effects, in which a part of the frequency pattern in a living field is transferred to and stabilized by a non-living, molecular structure.

Now we can take a second step in our analysis of the relationship between radiation and color. The radiation transmits energy and definite frequencies to certain chemicals in the retina, and

chemical hormones, characterized by definite frequency patterns, are formed. Some of the vibrations in the hormones are in resonance with vibrations in the "living fields" or "living wave systems" in the ganglia, and these fields, which have *slowly* expanded in the retina during the embryonic development of the optic cup from brain substance, absorb energy, and the vibrations are quickly amplified. This causes a *sudden* expansion of the living fields in the optic ganglia and their associated nerve fibers, an expansion which can be directly observed as a progressive change in the field structure *outside* the nerve fibers. There is now no longer the best possible fit between the electrical fields of the molecules and the structure of the living fields. The vital "holes" in the latter are no longer occupied by material elements, and a strange thing then happens. *The gate to the "universal realm of colors" is temporarily left ajar, and we have a glimpse in our consciousness of a color or a combination of colors.*

This may at first seem a strange explanation of the origin of colors. But a little reflection tells us that colors can not emerge spontaneously through a property of the molecular structure in the optic ganglia or in the brain. Colors must have an ultimate origin, in some way associated with the origin and potential structure of the color genes in the ovum and in the race. (This has an important bearing on the origin of sense organs and of life.) Although the nerve cells which the biologists and the physiologists study in their microscopes are shadows and nothing else, these shadows have a *meaning.* They are symbolic of something which we can only picture by an imagery developed by experience and conditioned by *our* type of intellect. We now picture the nerve cells as points of "contact" between the space-time world and another "world" or "dimension of Cosmos." The pictures we have are, of course, imperfect and inadequate, but they give us, in symbolic form, at least, some faint idea of the mechanism involved in the emergence of color through radiation, and of the relationship between matter and mind in general.

Neurones are peculiar elements in our bodies. When a neurone is stimulated, it always reacts in the same way, no matter how the stimulation is brought about. The optic ganglia can be stimulated by chemicals, or by pressure, or by electrical excitation, and they then give us sensations of color, but never anything else. The same holds for the nerve cells which give us sensations of sound, taste, smell and so on.

If the theory here presented is correct, it follows that *certain neurones have a consciousness of their own.* This consciousness is ordinarily associated with the general consciousness in the animal, and the associations are in the space-time world of our vision observable as neural connections and impulses. An excised optic ganglion, if it could be kept alive *in vitro* and properly stimulated, should therefore be capable of conscious color sensations. Other isolated neurones, if kept alive and stimulated, should give sensations of smell, others of taste, others of touch, and others of sound of a particular pitch. Systems of detached neurones may give feelings of pain and pleasure, and perhaps even of some simple type of emotion, although, of course, their former owner would be completely unaware of the new experiences in his one-time neural equipment. It is obviously impossible to get conclusive evidence of a consciousness in systems detached from the observer, but the behavior of some simple animals when touched, the effect of color-sensitive spots in the skin of animals, and the transplantation of eyes, with rebuilding of a retina and restoration of brain connections and sight, give some indication of the truth of this asser-

tion. The idea that man is an organized colony of simple animals is not foreign to biologists; in fact, we may well regard each of our cells and some of our organs as individual "animals." But the idea that our mind may be an organization of units having a consciousness of their own is a startling result of this analysis and leads to interesting conceptions regarding the nature and properties of our *general consciousness*,[5] which we may well call our "soul."

We have said that the atoms in the optic nerve cells keep the gates to the realm of color closed under normal conditions. The matter in the nerve cells in our brain can be expected to act in the same way and should therefore *restrain* rather than facilitate mental activities. (In this way we obtain a physical basis for Bergson's theory of memory.) Only a few of the gates to the non-physical world are open at any particular moment, and this fact prevents an avalanche of feelings, thoughts, and memories from descending upon our mind. Carried to its logical end, this idea can be used as a basis for the theory of the survival of the soul at death. Without matter and hormones with the right structures and vibrations, the living fields in our brain would shrink to a point. They would then disappear from the physical world of space and time, being submerged into the non-physical world from where they originally came. Our soul with all its memories would then not be annihilated at death; on the contrary, its capabilities would be much greater than when it was loaded down by inert matter. But if there is no time in the non-physical world, it is difficult to conceive of any actual development.

In the explanation of colors given above, we assumed that colors are irreducible elements, not only in our own minds, but also in *Cosmos*, that is, in a well-ordered and all-embracing universe. But it would be irrational to regard Cosmos as a *sum* of qualities, like space, time, colors, sounds, feelings, and thoughts. We have recently learned that space and time, which for our minds appear as completely different categories, in the external world form a more comprehensive unit, space-time. We have every reason to believe that *all* the attributes of Cosmos are interrelated and form a unified whole. It seems that the human and animal brains have elements originating in Cosmos and still retaining their association with their ultimate, world-transcending source and origin, the origin determining the physical structure as well as the non-physical qualities of the elements. Our brain is an instrument, operated by hormones, which does not of itself produce mental qualities, but *reproduces* certain structural and non-structural cosmic qualities. Therefore we observe Cosmos in the form of aspects, of which space is one, and time is another, color is a third, pain and pleasure are others. But Cosmos itself is one and indivisible, and it is due to a peculiarity of *our* mind and *our* nervous system that we picture it in the form of aspects and categories. When we look at a living brain we find structural properties originating in Cosmos. When we study our own mind, we find sensations, emotions, ideas, rules and relations. In both cases we study aspects of the same entity, a well ordered Cosmos. This is what the ancients called *The Soul of the Universe.*

B. Organizing Fields

Purposeful activity is characteristic of the human race and of many animals. In accordance with the ideas previously described, our conscious knowledge of such activities presupposes a similar faculty in Cosmos, a faculty which in my book I have called the *Cosmic Will.* We said before that both the structure and the functions of the nerve cells must be de-

[5] *Op. cit.*, chapter 11.

termined by immaterial and non-physical, that is, massless and structureless, sources originating in Cosmos. If this hypothesis is correct, it must be applicable to all kinds of organization in plants and animals. I shall here give a few examples of such organizing activities, referring interested readers to the more detailed analysis in my book.

In the embryonic development of all animals except Sponges and Protozoa a gastrula is formed by invagination of the blastula. The coordinated motions of the different parts of the embryo during gastrulation can obviously not be due to the molecular properties in any particular cell or cell group. Whether we like it or not, we must think of the motions as due to a guiding field (the source of which is probably centered in the region of the blastopore), which has some superficial similarity to a vortex system. A very characteristic property of the gastrula is that its parts, when transplanted into a new surrounding, for a time continue to change their shape as if they were still connected with the original field. This astonishing "persistence of activity" is quite foreign to our classical ideas of fields of force. A living field, like other guiding fields, is a space-time structure, but it differs in many ways from an ordinary electromagnetic field. The time element in an electromagnetic field is connected with the space elements by a certain constant conversion factor, the velocity of light. The changes in an electric field are therefore transmitted in space at a speed which we, with a stature of five or six feet and with a mental clock having a vibration period of about a tenth of a second,[6] naturally regard as tremendous. An electromagnetic field in which the sources have become neutralized therefore quickly disperses its energy in the form of radiation. In a living field there are not only rapid vibrations, evidenced by the incorporation of particular molecular structures, but also a progression which we, with our inherited standards, regard as "slow." The progressive changes we observe in embryonic development, for instance, reflect these slow changes in the field. A fraction of a living field, even when separated from its sources, can therefore for a while continue its normal development, because the dissipation of the energy in the field proceeds at a slow rate. Mechanical disturbances and high temperatures can be expected to increase the rate of dissipation. This slowness of some of the changes in living structures is responsible for the strange teleological properties in the development of living organisms, a purposeful development which is entirely incomprehensible from the standpoint of ordinary mechanics and electro-dynamics.

Spemann[7] introduced the term "organizing field" for the cause of the concerted activities which make possible the formation of a complete, highly organized animal. In the vertebrates this field seems to reside in latent form in the dorsal lip of the blastopore and spreads during gastrulation to the dorsal mesoderm. It induces the formation of nerve tissue in the neural plate which is underlaid by this mesoderm. In vertebrates the spreading influence in the mesoderm is observed as a formation of a notochord with somites, which seems to be the "root" or "stalk" from which the organizing field expands. At the beginning of the gastrulation the potential fields exist as dimensionless sources in the stagnation point of the "gastrula vortex." This point is in the dorsal lip of the blastopore and is well defined in many animals. The fields of these sources are developed under the influence of simple hormones (*e.g.*, oxygen) and interact with the *de Broglie* waves

[6] *Op. cit.*, pp. 176–180.

[7] H. Spemann, "Embryonic Development and Induction." Chapter XV. Yale University Press, 1938.

inherent in all matter. Because of this interaction with matter, the sources and their fields must follow the rapid cell flow in the immediate neighborhood of the stagnation point and are transferred to the mesoderm. These fields, when fully expanded, determine the structure and functions of the nervous system with its central organ, the brain, and its multitude of inter-connected neurones.

The division of an embryo into two new embryos is another indication that the living fields we study are of a type different from the non-living guiding fields. Before gastrulation begins we can divide an embryo, that is, we can make two complete replicas, by making a constriction in a median plane. The division is facilitated by shaking the fluid mass, which shows that the organized fluid matter exercises a stabilizing influence on the field. The primary effect seems to be a splitting of the potential notochord. The splitting ordinarily begins at its anterior end and may therefore result in the formation of two heads instead of two complete embryos. A complex guiding field can obviously not be split, because this splitting involves a complete duplication of tremendously complicated potentialities, as exemplified by our brain and our skull, and physical space has not enough dimensions for such a profound process, which must even involve a duplication of mental potentialities. The "splitting" must therefore occur in the non-physical world; in other words, it is the non-physical sources and not their fields which are split into two equal parts. During the very moment of splitting the sources must be dissociated from the energy patterns or fields they previously possessed, since these fields act as restraining bonds linking the sources with the physical world of space and time. If the processes of life are due to effects of living fields, the strange process we call *death* must be due to the disappearance of such fields from the physical world. In particular we conclude that when chromosomes are split during cell division, they actually die, but are immediately reborn in duplicate form. The first stages of the separation of the daughter chromosomes is caused by a progressive expansion of their living fields, in which process "The Exclusion Principle for Living Elements" (analogous to Pauli's Exclusion Principle for electrons) becomes effective.

In my book I have referred to the more complex sources, in particular those which produce organization by means of nerve systems, as *genii*. It seems to me a good name, but biologists would probably object to the connotation of mystery which this name implies. Many other names could be used, but in any event some name has to be adopted to represent the potential causes of organization fields and of mental qualities in living organisms.

Matter and life and consciousness have their "roots" in a world beyond space and time. They emerge into the physical world at certain well defined points or sources from which they expand in the form of guiding fields with space and time properties. Some of the sources can be identified with material particles, and others with the living elements responsible for organization and purposeful activities. Some of them exist in our brain as neurones, and some of them have a very intimate and special association with their ultimate origin. They are the roots of our consciousness and the sources of all our knowledge.

BOOKS ON SCIENCE FOR LAYMEN

CONFESSIONS OF A MATHEMATICIAN[1]

HARDY'S "Apologia pro Vita Sua" is ludicrously reminiscent of Cardinal Newman's famous history of his personal religious opinions. Unlike the late cardinal's pious effusion, however, Hardy's somewhat defiant challenge to the impure among mathematicians has a stimulating dash of satire occasionally, broadening into uproarious farce comedy in the final section. Hardy's sardonic confession of how he ever came to be a professional pure mathematician may be specially commended to solemn young men who believe they have a call to preach the higher arithmetic to mathematical infidels.

With his usual clarity the author explains several simple examples of what he calls "real" mathematical theorems. All are within the comprehension of any one who has had a few days of elementary algebra. Contrasted with "real" or stainlessly "pure" mathematics, is the baser kind, "useful" or applied mathematics, and we are shown why "pure mathematics is on the whole distinctly more useful than applied." This of course is an immediate corollary of a classic paradox of G. K. Chesterton's. We learn that when the mathematical physicist wants to be useful, "he must work in a humdrum way. . . . 'Imaginary' universes are so much more beautiful than this stupidly constructed real one. . . ." Well, God, not the mathematical physicist, must take the blame. And this brings us to what is perhaps the most remarkable passage in the book. It is a statement of Hardy's mathematical creed:

> I believe that mathematical reality lies outside us, and that our function is to discover or *observe* it, and that the theorems which we prove, and which we describe grandiloquently as our "creations" are simply our notes of our observations. This view has been held, in one form or another, by many philosophers of high reputation from Plato onwards. . . .

Indeed it has. But not by all. The impregnable strength of this creed is that it can be neither proved nor disproved. We may take it or leave it as we please. Congenital believers will embrace it with joy, possibly as a compensation for the loss of the religious beliefs of their childhood. Some, like Bertrand Russell, who once clung to it, will "abandon it with regret." The majority will probably ignore it as a museum piece from an incredibly credulous past.

The mathematician's apology, though franker and less casuistical than the cardinal's, deserves a place on the shelf with the churchman's masterpiece of special pleading. Even those who dislike what the mathematician says may like the enthusiastic way he says it.

E. T. BELL

[1] *A Mathematician's Apology.* G. H. Hardy. vii + 93 pp. $1.00. 1940. Cambridge University Press (Macmillan).

MENTAL COLLAPSE IN WAR-TIME[1]

IN the United States the importance of the subject of this book is indicated by the following aspect: According to official figures furnished through the courtesy of Dr. Martin Cooley of the Veterans' Administration, the approximate cost of paying compensation or pension to World War Veterans suffering from "Other Neuropsychiatric Diseases," which were preponderantly neuroses, was $28,703,928 for the fiscal year 1940. These cases numbered 54,364 and showed a steady increase from 1923 when they numbered 14,543; and their cost in that year was $5,793,420. Their total compensation cost for eighteen years from 1923 to 1940, inclusive, was $347,429,052. These were service connected cases and did not include psychotic patients. In addition to these compensation figures, the cost of hospitalization of neurotic patients, service connected and non-service connected, for the fiscal year 1940, was approximately $1,400,000.

[1] *The Neuroses in War.* Emanuel Miller, editor. xii + 250 pp. $2.50. 1940. The Macmillan Company.

In Great Britain in the early years after the 1914–1918 war, there were more than 100,000 neurotics receiving pensions for this disability, and the cost was roughly $40,000,000 annually.

Another aspect of this problem is the elimination of potential neurotics before they are admitted to the military service—a difficult task which can be only partially successfully performed, but in which the help of neuropsychiatrists is usually available if requested by local selective service boards and Army induction centers throughout the country.

Other aspects are the baleful effect of these neurotics on the morale of their associates; the care and treatment in the Army, the object of which is to return them to duty if possible, and if not, to discharge them; and last but not least perhaps, the problem of the neuroses among the civilian population.

It became an axiom in the first world war that the number of war neuroses ("shell shock" cases) was in the inverse ratio to the morale of a military organization. During the past year the small number of neuroses among the civilian population of Great Britain has been a matter of interest, comment and surprise. Probably the magnificent morale of the British nation has been a major factor here.

Unfortunately, this book, "The Neuroses in War," was written before the mass air raids on Great Britain were begun. However, it presents the digested experience of its numerous authors in the first world war, and is written with authority and with the object of application to current military and civilian war neurosis problems. While apparently intended primarily for physicians, there is much in it that the intelligent layman can grasp and will find interesting and profitable. The chapter on "The 'War of Nerves': Civilian Reaction, Morale and Prophylaxis," is admirable, both in content and style.

Roscoe W. Hall, M.D.

NATURAL HISTORY OF THE HONEYBEE[1]

In this book Mr. Teale has presented a well-written and fascinating account of the life of the honeybee embellished by many of his excellent photographs.

One of the earlier chapters discusses briefly the life histories of some of the solitary bees and of the other two groups of social bees—the stingless honeybees of the tropics and the bumblebees of the temperate regions. Later chapters take up the activities of the domesticated honeybee from spring to fall. There is a chapter discussing the morphology of the honeybee in a non-technical manner, and such morphological adaptations as the pollen-gathering apparatus and the "wax plates" are given due mention. Another chapter tells of von Frisch's classic experiments on the senses of bees proving that they have a definite perception of various colors and scents. The various enemies of bees such as the bee louse, wax moth, dragon fly, toad, skunk and others are the subjects of another section. The more important technical and popular books on apiculture and the life of the honeybee are discussed briefly near the end of the book. The final chapter entitled "Photographic Postscript" will be of interest to those having photography for a hobby as the author describes his equipment and the methods used to obtain the pictures illustrating his volume. A special word of praise should be said for Mr. Teale's photographs—the numerous pictures are distinguished for their sharpness and interesting subject-matter.

This book is recommended unhesitatingly for the layman who is interested in insects, though it should be understood that it is not a treatise on apiculture. The information contained is sound and the book should make excellent reading for high-school and college students of biology.

Karl V. Krombein

[1] *The Golden Throng.* Edwin Way Teale. Illustrated. 208 pp. $3.00. 1940. Dodd, Mead and Company.

ON THE SOCIAL DISEASES[1]

In the past few years much effort has been expended in attempts to acquaint the public with the nature of the two most significant venereal diseases: syphilis and gonorrhea. Unfortunately, the majority of books for laymen on this subject have been either malodorously sanctimonious, crucifying the innocent with the "guilty" and creating dangerous phobias through prudish mystery, or they have been prepared by "feature writers" with little knowledge of their subject. However, in this very recent volume on what the layman should know about gonorrhea and syphilis, we find that Dr. Irving Simons possesses the rare qualities of medical accuracy, keen and scientifically dispassionate sociologic evaluation and ability to explain in simple, non-technical language the natural history of these two infections.

The volume is divided into two parts, considering the two diseases separately. After describing the historical backgrounds, the author discusses the causes of infection, the microorganisms and the modes of transmission. Next are considered the diagnosis and consequences of the diseases. Methods of treatment and their limitations and potentialities are very well described in such manner that the lay reader will not be encouraged to attempt self-medication (a frequent cause for delay in the institution of proper medical management and also an important factor in enhancing the chances of complications in gonorrhea). The importance of prompt medical attention is stressed effectively. One is most favorably impressed by the sane clarity and simplicity with which these problems are discussed.

The lay public interested in obtaining accurate information concerning these serious diseases is to be congratulated upon now having available this excellent book. The style is lucid, precise and flowing. There are no sentimental outbursts or exaggerations. The scientific facts are sound. Despite the simplicity of the language, one does not have that disagreeable feeling that the reader is being talked down to and his intelligence insulted by infantile phraseology, so often a major source of irritation in so-called "scientific" books for laymen. There is some unnecessary repetition which may well be avoided in future editions.

The book can be read with profit by all non-medical persons concerned with venereal disease, such as officers of the Army and Navy, personnel executives, sociologists and teachers. Physicians can and should recommend it to their venereal disease patients; its study should improve the results of treatment by enabling the patient to understand it more fully and thus cooperate more effectively. It is too sane and honest to appeal to bigoted reformers who would deny that mankind is biological. As Clarence Day whimsically told us: If we have fallen from the angels, we have indeed fallen far; if we have risen from the ranks of other species, mankind has done pretty well. We must not expect that venereal disease will or can be eradicated by purely sociologic "policing." But there is every reason to hope that the science of medicine may some day find much more efficient methods for cure and also of prevention, possibly by specific prophylactic immunization, such as has been accomplished with smallpox and/or diphtheria. In many respects syphilis is the less destructive of the two diseases. Despite the misleadingly suggestive title of Dr. Simons's book, "Unto the Fourth Generation," there are far fewer "damaged goods," or congenital syphilitic stigmata, than is generally believed, due to nature's selective protection by insuring that the truly unfit shall not survive, and to the great art of medicine.

EDWARD J. STIEGLITZ, M.D.

[1] *Unto the Fourth Generation: Gonorrhea and Syphilis.* Irving Simons. Illustrated. xiv + 243 pp. $2.50. 1940. E. P. Dutton and Company.

WALTHER NERNST IN 1934

THE PROGRESS OF SCIENCE

WALTHER NERNST, A GREAT PHYSICIST, PASSES

IN the spring of 1896 the new Institute of Physical Chemistry at Göttingen was dedicated with the thirty-year-old Walther Nernst as director. Arrhenius was the chief speaker and guest of honor. There were seventeen of us advanced students in that laboratory that spring, sixteen of whom called themselves physicists and one a chemist. Six of the seventeen were Americans. All of us "sat in" on Nernst's general lectures which covered the material in his new book on "physical chemistry" upon which his reputation at that early age had largely been built. That book was notable in its grasp of the physics of the day with enough of chemistry to justify the title. The group in the laboratory regarded Nernst as essentially a physicist, well endowed with physical ingenuity and insight and a moderate knowledge of analytical procedures, who had had the ability to get a new laboratory built for himself by capitalizing on the recent discovery by chemists under the lead of Ostwald (Nernst had been with him at Leipzig) of what physics had been doing throughout the nineteenth century.

Nernst himself would not quarrel with the foregoing estimate even though it might seem a bit extreme. Nernst himself was a man of extremes. As a student he had spent his first two years at the university in "bummeling" as a typical member of one of the "fighting corps," the record of which showed in the scars on his face, acquired in his "mensur duels."

After his "bummeling" period he settled down to work intensively and acquired the grasp which gave him the standing, as well as the academic post, which he had won at the early age of thirty. His reputation at that time rested primarily upon his newly published book, psychologically well timed, and his design of a modification of the Wheatstone's bridge. This made it possible to balance out the capacities as well as the resistances of the arms of the bridge and thus improved the measurement of the dielectric constants of solutions, for example. He was a little fellow with a fish-like mouth and other well-marked idiosyncrasies. However, he was in the main popular in the laboratory, despite the fact that in the academic world he nearly always had a quarrel on with somebody. He lived on the second floor of the institute with his wife and three young children. As we students came to our work in the morning we would not infrequently meet him in his hunting suit going out for some early morning shooting.

He assigned and supervised most, though not all, of the problems going on in his laboratory. He was at that time working on the "Nernst lamp," which later brought him excellent commercial returns. I did some work there at his suggestion on the dielectric constants of emulsions. After my return to the United States I sent him the experimental results and included in the discussion of them an attempt to develop a theory not then in the literature of the anomalous dispersion of short electromagnetic waves. Nernst separated the theoretical part of the article from the experimental, sent the latter to the *Annalen der Physik*, and returned to me the former with the comment that he did not feel competent to pass on its validity and the suggestion that I try to get further tests of the theory and then send it in independently. Drude was at that time editor of the *Annalen* and the author of the current theory of anomalous dispersion. He published at once the experimental article, drew from it the same

conclusion I had reached as to the inapplicability of his theory to such cases as those with which I was concerned and being entirely unaware of my theoretical work, developed exactly my equations, though with greater elegance than I had used, and published the new theory with due acknowledgment that he had got the suggestion for his article from my paper found in the preceding issue. The incident furnishes a bit of evidence that Nernst's greatest strength was in physical insight rather than in theoretical analysis.

Nernst had been in Göttingen but a few years when he accepted the directorship of the Institute of Physical Chemistry at Berlin. I again saw much of him there in the summer of 1912 when I found many more students attending his lectures than in Göttingen days. Excellent work too was going on in his laboratory, particularly on specific heats at low temperatures. This was the field in which his physical insights—his hunches—were most successful. At this time we were all trying to unravel the intricacies of the quantum theory, and specific heats showed us not only that equipartition had to break down, but just how it broke down. The third law of thermodynamics formulated at about this time is unquestionably the greatest monument to Nernst's scientific insight. He had some bad hunches in the field of cosmic-rays and the amount of energy he expended in his later years in trying, under the stimulus of the commercial motive, to develop a pure-toned piano, represented, so I always thought, very bad judgment, but *the third law of thermodynamics is enough to give him a seat among the immortals.*

His greatest weakness lay in his intense prejudices and the personal, rather than the objective, character of some of his judgments. An incident of 1912 illustrates. He had been entertaining me in most friendly way that summer and he was at that time preparing a new edition of his chemistry. I had just brought my work on *e* to what I thought a dependable conclusion. He asked me if I would not write that chapter of his new edition for him. I did so and of course had to deal with the work of others as well as of myself. He had recently come back from the first meeting of the Solvay Congress, at which Perrin, who preceded Nernst on the program, had consumed so much of Nernst's time as to greatly enrage him. He accordingly gave instructions to have Perrin's name expunged completely from the new edition of his book.

In 1931, when he was occupying the altogether logical post of director, now, not of the Institute of Physical Chemistry but of Physics, in the University of Berlin, he drove me through the city in his single-seated automobile. The quite vigorous and uncontrolled way in which he berated other drivers who, as he thought, got in his way, seemed to me an illustration of the way age in general tends to intensify the weaknesses which to some extent we have sometimes been able to hold in check in our earlier days. In Nernst's case the objectiveness of science made little headway against the intense prejudices of the Prussian.

Politically Nernst remained a Prussian of the Prussians—a strange mixture of the virtues and the vices of his race.

Robert A. Millikan

THE AMERICAN ASSOCIATION CARRIES ON

In spite of the direct involvement of the United States in the World War, the American Association for the Advancement of Science and thirty-nine of its affiliated societies will hold their planned meeting in Dallas, Texas, from December 29 to January 2. The decision to go forward with the meeting does not

imply that the officers of the association think that science is something wholly apart from the currents of life. On the contrary, the decision rested on the fact that science is producing a strong tide that is carrying civilization forward although now and then, as at present, storms produce tumultuous waves on its surface.

So rapid has been the development of science that it is impossible to realize its importance in human affairs. Too often we think of Archimedes, serenely drawing geometrical figures in the sand when Syracuse was sacked by the Romans in 212 B.C., as the typical scientist wholly aloof from the world and wrapped up in abstract speculations. Even on the abstruse work of Archimedes, history has placed its stamp of approval. But not only are scientists of the present day carrying on investigations of the fundamental properties of the universe, but they are making direct contributions of the highest importance to the national defense. Many members of the association will not attend the Dallas meeting because of their services to the Government. They have not been drafted; they have volunteered and have accepted any assignments that have been offered. Those who are carrying on their regular work sometimes may envy those in defense service, while the latter long for the days when they can return to their usual work.

It is often assumed that only a few sciences are directly involved in national defense. As a matter of fact, there is probably no broad field of science which is not making important contributions. Consider mathematics, the field of the first of the fifteen sections under which the work of the association is organized. Even if one knew precisely what is being done in each field at present, it would be improper to make it public. But there was no such limitation on the contribu-

DR. GORDON T. WHYBURN
PROFESSOR OF MATHEMATICS, UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE; CHAIRMAN OF THE SECTION ON MATHEMATICS.

DR. RICHARD C. TOLMAN
PROFESSOR OF PHYSICAL CHEMISTRY AND MATHEMATICAL PHYSICS, CALIFORNIA INSTITUTE OF TECHNOLOGY; CHAIRMAN, SECTION ON PHYSICS.

DR. EDWARD A. DOISY
PROFESSOR OF BIOCHEMISTRY, SCHOOL OF MEDICINE, ST. LOUIS UNIVERSITY; CHAIRMAN OF THE SECTION ON CHEMISTRY

DR. EDWIN P. HUBBLE
ASTRONOMER AT THE MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION; CHAIRMAN OF THE SECTION ON ASTRONOMY.

tions of science during the first world war. In that war mathematicians proved that the methods which had been developed for following the motions of planets were highly advantageous in calculating the flights of projectiles and bombs.

As to physics there is no question, for more than half the physicists in the United States are devoting at least part of their time on work for the Government, and the situation is nearly the same for the chemists. But it is natural

DR. MORRIS M. LEIGHTON
CHIEF, ILLINOIS STATE GEOLOGICAL SURVEY DIVISION; CHAIRMAN OF THE SECTION ON GEOLOGY AND GEOGRAPHY.

to assume that astronomy can have no practical applications, except in navigation, in time of war. Yet during the first world war it made a very interesting and important contribution. As is illustrated on page 94 of this journal, the stars can be photographed through telescopes. This fact led directly in this country to a solution of the very difficult problem, then presented for the first time, of finding the height at which anti-

aircraft projectiles explode when fired under specified conditions and armed with fuses with given time settings. The problem was solved by photographing at night through two telescopes some hundreds of yards apart the explosions of projectiles against the background of stars whose positions with respect to one another are fixed and precisely known. From the apparent positions of the projectile explosions among the stars and the precise times of explosion (for the stars apparently move with the rotation of the earth), the heights of the explosions were readily computed.

Let us not, however, permit our perspective to be distorted by the exigencies of the hour. Many addresses by distinguished scientists will be delivered at Dallas and many important symposia will be presented. Among the addresses those of the vice-presidents of the association, whose portraits are reproduced here, will be outstanding. There is a

DR. J. T. PATTERSON
PROFESSOR OF ZOOLOGY AND DIRECTOR OF ZOOLOGICAL RESEARCH, UNIVERSITY OF TEXAS; CHAIRMAN, SECTION ON ZOOLOGICAL SCIENCES.

DR. GILBERT M. SMITH
PROFESSOR OF BOTANY, SCHOOL OF BIOLOGICAL SCIENCES, STANFORD UNIVERSITY; CHAIRMAN OF THE SECTION ON BOTANICAL SCIENCES.

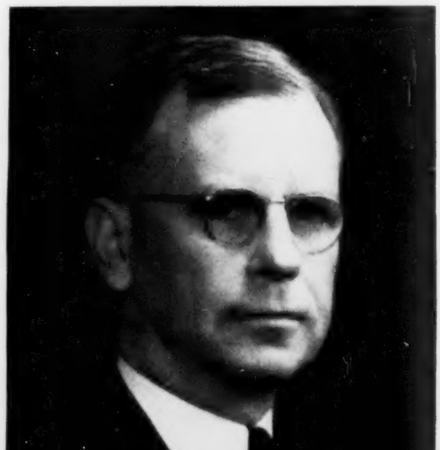
DR. GEORGE C. VAILLANT
DIRECTOR OF THE UNIVERSITY MUSEUM, UNIVERSITY OF PENNSYLVANIA; CHAIRMAN OF THE SECTION ON ANTHROPOLOGY.

DR. EDMUND S. CONKLIN
PROFESSOR AND HEAD OF THE DEPARTMENT OF PSYCHOLOGY, INDIANA UNIVERSITY; CHAIRMAN OF THE SECTION ON PSYCHOLOGY.

vice-president of the association for each of the fifteen sections. Each vice-president is the chairman of his section and delivers a vice-presidential address, usually at the conclusion of his term of office, on some aspect of the subject of his section. These addresses are published in *Science* and constitute a valuable record of the progress of science. The presidents of many of the affiliated societies also deliver addresses which are usually published in *Science*.

As illustrations of the addresses of retiring vice-presidents, the following will suffice: Dr. George Scatchard, retiring vice-president for the Section on Chemistry, will deliver an address on "The Application of Chemistry to Biological Problems." Dr. J. T. Patterson, vice-president for the Section on Zoological Sciences, will deliver an address on "Drosophila and Speciation." Dr. W. Duncan Strong, retiring vice-president for the Section on Anthropology, will

DR. JOSEPH MAYER
HEAD, CONSUMER INCOME AND DEMAND UNIT, OFFICE OF PRICE ADMINISTRATION; CHAIRMAN FOR HISTORICAL AND PHILOLOGICAL SCIENCES.



DR. E. W. GOODPASTURE
PROFESSOR OF PATHOLOGY, VANDERBILT UNIVERSITY SCHOOL OF MEDICINE; CHAIRMAN OF THE SECTION ON MEDICAL SCIENCES.

deliver an address on "Recent Archeological Research in Latin America." The addresses of the retiring vice-presidents for the sections on psychology and education will be delivered at a joint session of the two sections. Dr. Karl M. Dallenbach, vice-president of the former section, will speak on "The Temperature Senses: Their History and Present Status"; the subject of Dr. E. J. Ashbaugh, vice-president for the latter section, is "Education as Science and Art."

From the very nature of its organization the American Association for the Advancement of Science is an integrating agency in science; and because of the breadth of its interests, its large membership (more than 23,000) and the number of its affiliated and associated societies (now 182), it is the most effective agency for the purpose in the world. It achieves its ends in various ways: it is the bringing together of scientists from many fields—thirty-nine independent societies in Dallas in addition to the

DR. HAROLD F. CLARK
PROFESSOR OF EDUCATION, TEACHERS COLLEGE, COLUMBIA UNIVERSITY; CHAIRMAN OF THE SECTION ON EDUCATION.

DR. R. L. SACKETT
EMERITUS DEAN OF ENGINEERING, PENNSYLVANIA STATE COLLEGE; ACTING CHAIRMAN OF THE SECTION ON ENGINEERING.

DR. RICHARD BRADFIELD
PROFESSOR AND HEAD OF THE DEPARTMENT OF AGRONOMY, CORNELL UNIVERSITY; CHAIRMAN OF THE SECTION ON AGRICULTURE.

sections of the association; it holds general sessions at which the president of the association and other distinguished scholars deliver addresses of broad general interest; it provides opportunities for the organization of joint symposia by groups who have important interests in common—twenty-five such symposia at the Dallas meeting; and it publishes the most important symposia. It is difficult to measure the importance of such contributions to science, especially in times of stress, but it is certain that they are forces of the kind that have revolutionized the world. Marching armies have their triumphs and their defeats, largely on the physical plane, but ideas are lodged and grow and mature in the unconquerable and irresistible depths of the mind.

F. R. Moulton,
Permanent Secretary

THE MEMORIAL TO MARCONI

A small triangular park, looking down the meridian of Washington toward the Executive Mansion, is being converted to an American national memorial to a man who by birth—and by burial—belonged to another nation, but whose achievements in the field of science and contributions to the progress of the human race made him a citizen of the world.

In granite and bronze, the memory and accomplishments of Guglielmo Marconi, inventor of wireless telegraphy—the medium of communication which reduced time to an instant, encompassed all space and surmounted the barriers of mountain and sea—will be forever enshrined. In this dark period of the world's history, it is encouraging to note that a nation befogged by rumors of war and reports of destruction finds pause to pay tribute to one who dedicated his labors to advance the standards of civilization.

THE NEW MEMORIAL TO MARCONI

The Marconi Memorial will take the form of a double pedestal of Stony Creek granite, arising from a base of the same material. The lower of the two pedestals will support a bronze bust of the inventor. Behind this pedestal and bust will arise a broader and taller pedestal surmounted by the bronze figure of a woman carried on a half globe suspended in clouds, through which ethereal waves are passing. The sculptor, Attilio Piccirilli, has interpreted the work in the following words:

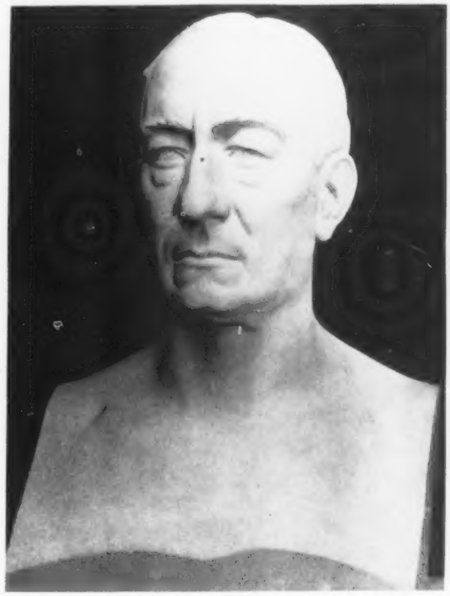
> Against the shaft of the monument, on a base of classic simplicity, rests the bust of Marconi, as firmly planted as his fame. The head, modeled in its virile strength, stresses purposefulness in the line of the mouth, and vision in the far-seeing eyes under the great brow.
>
> Symbolic of Marconi's contribution to science, the Wave speeding through ether covers the earth. There is the fleetness of lightning in the backward sweep of hair and drapery. There is direction in the outthrust arm guided by the noble head which, as the figureheads of the ships dominated the sea, now commands the heavens. With Promethean gesture the uplifted hand reaches for still greater gifts to man.

The memorial will be imposing in its grace and dignity and the beauty of its setting, rather than in its size. The pedestal holding the bust of the inventor will be only seven feet high and the bust three feet eight inches. The taller pedestal will be 13 feet 5 inches high, with the symbolic figure rising nine feet above.

The small park which provides the site for the memorial is located on the west side of 16th Street at Lamont Street, N. W., in Washington. The monument will be placed close to the north border of the park and will face the south. It will be approached by a curved walk leading from the south point of the triangle, along the west hypotenuse and crossing in front of the memorial, where it will form a paved plaza, exiting toward 16th Street on the east. Benches will be spaced along the walk to face toward the memorial. They will be shaded by American elms and backed by small hedges of evergreen barberry. Across the walk and bordering the lawn area, a low hedge of evergreen privet will lead toward the monument. Flowering dogwood trees will line the hedge at studied intervals.

The memorial will be flanked on either side by low-spreading yews and Washington thorns. Firethorns, dwarf yews and small-leaf holly will provide a low hedge behind the memorial. Japanese spurge will be used as ground cover. The entire composition will be enframed by flowering dogwoods. The landscaping treatment has been designed to take advantage of the four existing mature American elms which form a fine canopy along Lamont Street behind the memorial, and the existing silver maples which guard the 16th Street boundary.

The sculptor, Attilio Piccirilli, was born in Massa-Carrara, Italy, in 1866. He studied at the Academia San Luca in Rome before coming to the United States in 1889. Among his better-known works are the Maine Memorial in Central Park, New York; the MacDonough Memorial in New Orleans and the Fireman's Memorial on Riverside Drive, New York. He is represented in the Fine Arts Academy, Buffalo, by Dancing Faun and Head of Boy. His other works include Apgar Memorial; A Soul; Flower of the Alps; Portrait of an Artist; Mater Consolatrix; Pediment, Frick House; Mater Amorosa and the Pariah of the Church of St. Marks-in-the-Bouverie, New York.



BUST OF MARCONI IN THE MEMORIAL

The architect for the memorial is Joseph H. Freelander, New York. Joseph C. Gardner, of Bethesda, Maryland, is the landscape architect. The memorial is being erected under authority of Congress by the Marconi Memorial Foundation of New York. Officers of the foundation are Generoso Pope, president; S. Samuel Di Falco, secretary-treasurer; John J. Freschi, Armerindo Portfolio and Ruigi Criscuolo, vice-presidents.

The man whose inventive achievements the memorial will commemorate was born in Bologna, Italy, on April 25, 1874, of an Italian father and an Irish

STAR CLOUD IN MILKY WAY

A FEW OF THE THOUSANDS OF MILLIONS OF STARS IN OUR OWN STELLAR SYSTEM. MILLIONS OF SIMILAR STELLAR SYSTEMS ARE KNOWN WHICH ARE SO DISTANT THAT MILLIONS OF YEARS ARE REQUIRED FOR THEIR LIGHT TO COME TO US.

mother. During and after his education at Bologna, Florence and Leghorn, he was interested in physical and electrical science. In 1895, when he was 21, he became convinced that a system of telegraphy through space could be provided by means of electromagnetic waves, the existence of which had been foreseen mathematically by Clerk Maxwell in 1864.

After experimenting at his father's estate in Bologna, young Marconi went to England, where on June 2, 1896, he took out the first patent ever granted for wireless telegraphy based on the use of electric waves. That same year he demonstrated his invention to government officials, and in March, 1898, he sent a message across the English channel from England to France. Naval and military uses of his invention followed, and on December 12, 1901, Marconi, on his first attempt, succeeded in transmitting and receiving signals across the Atlantic from Poldhu in Cornwall, England, to St. John's, Newfoundland.

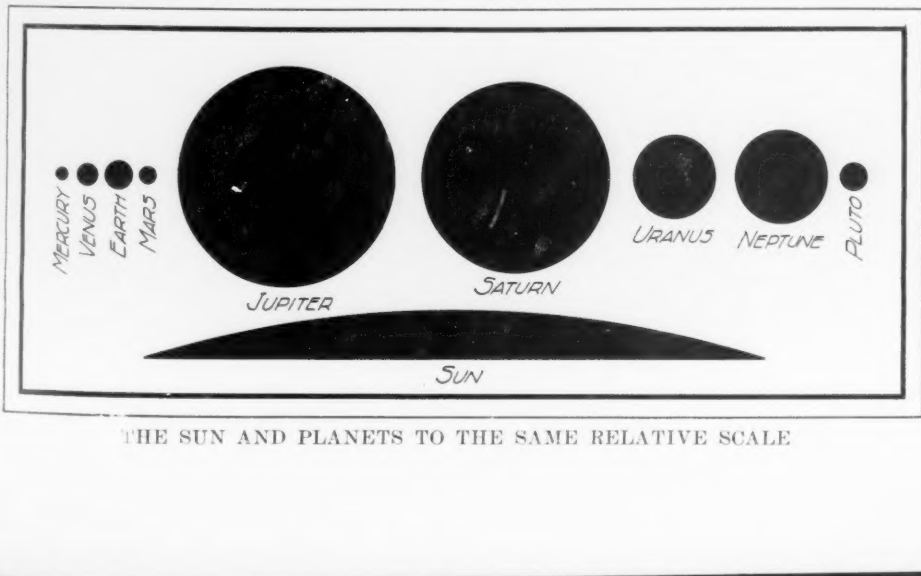
Marconi was awarded the Nobel Prize for physics in 1909, the Albert Medal of the Royal Society of Arts, and, in the United States, the Franklin and the John Fritz Medals.

EDWARD KELLY

THE EVENING SKY

NOT often is the evening sky more beautifully sprinkled with planets and stars than during these winter months. As soon as the sun sets, and it now sets early, the most casual observer is almost startled by the white brilliance of Venus in the western sky. Toward the south red Mars stands out conspicuously from the stars, while in the east Jupiter rises and shines only second to Venus, and above Jupiter and a little to the right is ringed Saturn. These bodies are not stars but planets that, like the earth, revolve around the sun. The stars, other suns, are not lacking, for in the southeast is Sirius, the most brilliant star in the sky, and above it are Rigel and the glorious stars that make up the Belt and the Sword of Orion.

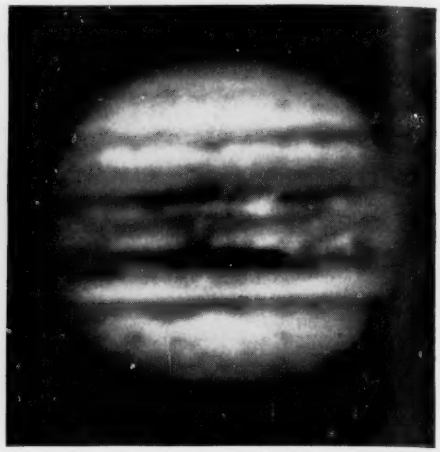
Although the planet Venus is apparently much brighter than any red star in the sky, it is actually much smaller than any of them and appears luminous only because it reflects some of the light it receives from the sun. It is a little world, somewhat smaller than the earth and somewhat nearer the sun. Its year is about 225 of the earth's days in length, but the length of its day is uncertain because it is surrounded by a cloud-filled



THE SUN AND PLANETS TO THE SAME RELATIVE SCALE

THE RINGED PLANET SATURN

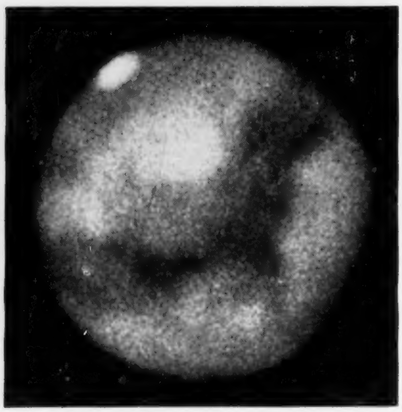
A SILVERY OBJECT A SHORT DISTANCE NORTHEAST OF MARS IN THE SOUTHERN SKY; 75,000 MILES IN DIAMETER WITH AN AVERAGE DENSITY LESS THAN THAT OF WATER. THIS PHOTOGRAPH WAS TAKEN AT THE LOWELL OBSERVATORY IN 1912 THROUGH A YELLOW COLOR FILTER.



THE GIANT PLANET JUPITER

NOW VISIBLE IN THE EAST IN THE EVENING; A TENUOUS MASS OF GAS 88,000 MILES IN DIAMETER, MAKING IT LARGER THAN ALL THE OTHER PLANETS PUT TOGETHER. IT IS FIFTH IN ORDER OF DISTANCE FROM THE SUN. THE PHOTOGRAPH WAS TAKEN AT THE LOWELL OBSERVATORY.

atmosphere that always hides its surface. It is its relative nearness to the sun and its highly reflective atmosphere that make it so bright as seen from the earth. Since it revolves around the sun in an



THE RED PLANET MARS

NOW VISIBLE IN THE SOUTHERN SKY EARLY IN THE EVENING; A WORLD HALF THE DIAMETER OF THE EARTH, HAVING A DAY ABOUT THE SAME LENGTH AND A YEAR NEARLY TWICE AS LONG. THE PHOTOGRAPH, SHOWING DARK EQUATORIAL BELTS AND WHITE POLAR CAPS, WAS TAKEN AT THE YERKES OBSERVATORY WITH THE GREAT 40-INCH TELESCOPE.

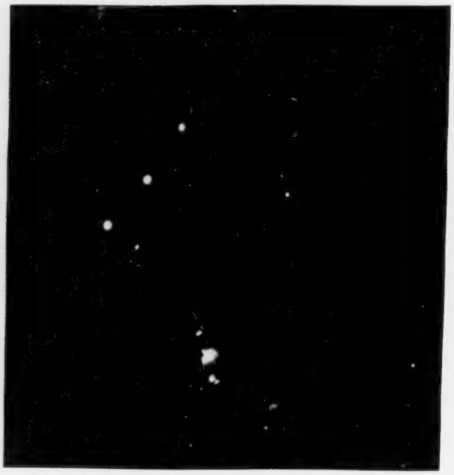
orbit that is interior to that of the earth, its distance from the earth varies greatly. When it is between the earth and the sun it is invisible because its dark side is toward the earth. When it is on the opposite side of the sun it is invisible because it is lost in the sun's brilliant rays. Now, as we see it, it is east of the sun, following the setting sun down to the western horizon, and when observed through a telescope appears as a crescent with its convex side toward the sun. It will be at its brightest on December 28 when it can readily be seen, if one knows just where to look for it, before the sun has set and even at noon. But it is rapidly moving between the earth and the sun, to reappear in a few months on the other side as an equally conspicuous object in the eastern sky before the sun rises. It will not be a brilliant object in the evening again until the summer of 1943.

Jupiter, now in the eastern sky, is more than a thousand times as great in volume as the earth or Venus. It is less brilliant than Venus, both because it is

THE GREAT ORION NEBULA
A MASS OF GLOWING GAS, WHOSE DIAMETER IS 40,000,000 TIMES THE DISTANCE FROM THE EARTH TO THE SUN AND WHOSE DISTANCE IS SIXTY TIMES ITS DIAMETER.

farther from the sun, and consequently less intensely lighted, and because it is five times as far from the earth. Saturn is another large planet, though not quite so large as Jupiter, but noted for its enormous ring system and its nine moons, one of which revolves around it in the direction opposite to its rotation.

Of all the planets, Mars is the one that has been of greatest popular interest because of the markings that can be seen on its surface and of the speculations about its being the abode of life, possibly of a high order of development. The diameter of this world is only a little more than half that of the earth, its day is a little more than 24 hours in length, and its year is nearly two of our years. Its atmosphere is as tenuous as that on the earth's loftiest mountain peaks and no oceans are spread over its surface. If there is life on Mars, especially higher forms, it must be quite unlike the life on the earth, for the environment of this life would be different in many important respects. To reproduce itself and



BELT AND SWORD OF ORION

NOW VISIBLE IN EARLY EVENING IN SOUTHEASTERN SKY. THE THREE DIAGONAL BRIGHT STARS FORM THE BELT; THE THREE VERTICAL STARS BELOW FORM THE SWORD; THE CENTRAL ONE IS SHOWN IN LARGER SCALE IN THE PRECEDING PICTURE. ALL THESE STARS ARE SO DISTANT THAT THE LIGHT WITH WHICH THIS PHOTOGRAPH WAS TAKEN LEFT THEM SEVERAL HUNDRED YEARS BEFORE PHOTOGRAPHY WAS INVENTED.

endure, it evidently would have to be adapted to the conditions surrounding it.

In a troubled world, the planets shining in the evening sky at the Christmas season this year arouse in us wonderment and vague yearnings that Sir Alfred Noyes, in his "Watchers of the Sky," personified in the planets themselves, the Earth saying:

Was it a dream that, in those bright dominions,
Are other worlds that sing, with lives like mine,
Lives that with beating hearts and broken
pinions
Aspire and fall, half-mortal and half-divine?
A grain of dust among those glittering legions—
Am I, I only, touched with joy and tears?
O, silver sisters, from your azure regions,
Breathe, once again, your music of the
spheres:—

"A grain of dust among those glittering legions"! Those glittering legions to which Sir Alfred refers are the sparkling stars that are brightest and most numerous in the winter and early spring months. Instead of being "silver sisters" of the earth, small bodies revolving around our sun or some other sun, they are suns themselves, almost always a million times as large as the earth and Venus and even Jupiter. Like our sun, these enormously hot bodies radiate light and heat at an inconceivably rapid rate. They appear to be mere points of light because of their enormous distances. Even Sirius, the nearest star visible from northern latitudes, is so distant that the light from it which reaches our eyes when we now look at the southeastern sky in the evening has been on its way more than four years. The light of most of the stars we see has been speeding for hundreds of years through the immensities of space before it encounters this "grain of dust among those glittering legions."

F. R. M.